March 2003

# Environmental Technology Verification Report

## YSI INCORPORATED 6600 EDS MULTI-PARAMETER WATER QUALITY PROBE/SONDE


Prepared by
Battelle

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In cooperation with the
National Oceanic and Atmospheric Administration

Under a cooperative agreement with

EPA U.S. Environmental Protection Agency


ETV ETV ETV

March 2003

# Environmental Technology Verification Report

## ETV Advanced Monitoring Systems Center

## YSI Incorporated
## 6600 EDS Multi-Parameter
## Water Quality Probe/Sonde


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# Notice

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# Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the nation's air, water, and land resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, the EPA's Office of Research and Development provides data and science support that can be used to solve environmental problems and to build the scientific knowledge base needed to manage our ecological resources wisely, to understand how pollutants affect our health, and to prevent or reduce environmental risks.

The Environmental Technology Verification (ETV) Program has been established by the EPA to verify the performance characteristics of innovative environmental technology across all media and to report this objective information to permitters, buyers, and users of the technology, thus substantially accelerating the entrance of new environmental technologies into the marketplace. Verification organizations oversee and report verification activities based on testing and quality assurance protocols developed with input from major stakeholders and customer groups associated with the technology area. ETV consists of seven environmental technology centers. Information about each of these centers can be found on the Internet at http://www.epa.gov/etv/.

Effective verifications of monitoring technologies are needed to assess environmental quality and to supply cost and performance data to select the most appropriate technology for that assessment. In 1997, through a competitive cooperative agreement, Battelle was awarded EPA funding and support to plan, coordinate, and conduct such verification tests for "Advanced Monitoring Systems for Air, Water, and Soil" and report the results to the community at large. Information concerning this specific environmental technology area can be found on the Internet at http://www.epa.gov/etv/centers/center1.html.

# Acknowledgments

The authors wish to acknowledge the support of all those who helped plan and conduct the verification test, analyze the data, and prepare this report. We would like to thank the National Oceanic and Atmospheric Administration's (NOAA's) National Ocean Service, National Centers for Coastal Ocean Science staff at the Center for Coastal Environmental Health and Biomolecular Research. In particular, we recognize Paul Pennington and Jennifer Tobias for their outstanding efforts. In addition, NOAA's Coastal Service Center is acknowledged for providing access to dock facilities on the Cooper River for the saltwater testing portion of this study. We also acknowledge the assistance of the ETV Advanced Monitoring Systems Center stakeholders Vito Minei, Christine Kolbe, and John Carlton.

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# List of Abbreviations

| | |
|---|---|
| AMS | Advanced Monitoring Systems |
| CCEHBR | Center for Coastal Environmental Health and Biomolecular Research |
| cm | centimeter |
| DAS | data acquisition system |
| DO | dissolved oxygen |
| EDS | Extended Deployment System |
| EPA | U.S. Environmental Protection Agency |
| ETV | Environmental Technology Verification |
| L | liter |
| μg | microgram |
| mg | milligram |
| mS | millisiemen |
| NIST | National Institute of Standards and Technology |
| NOAA | National Oceanic and Atmospheric Administration |
| NTU | nephelometric turbidity unit |
| PE | performance evaluation |
| QA | quality assurance |
| QA/QC | quality assurance/quality control |
| QMP | Quality Management Plan |
| RSD | relative standard deviation |
| TSA | technical systems audit |

# Chapter 1
# Background

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high-quality, peer-reviewed data on technology performance to those involved in the design, distribution, financing, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized testing organizations; with stakeholder groups consisting of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance (QA) protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

The EPA's National Exposure Research Laboratory and its verification organization partner, Battelle, operate the Advanced Monitoring Systems (AMS) Center under ETV. The AMS Center recently evaluated the performance of the YSI Incorporated 6600 Extended Deployment System (EDS).

# Chapter 2
# Technology Description

The objective of the ETV AMS Center is to verify the performance characteristics of environmental monitoring technologies for air, water, and soil. This verification report provides results for the verification testing of the 6600 EDS water probe by YSI Incorporated. Following is a description of the 6600 EDS, based on information provided by the vendor. The information provided below was not verified in this test.

The 6600 EDS is a multi-parameter water probe/sonde capable of measuring dissolved oxygen (DO), conductivity, temperature, pH, turbidity, and chlorophyll.

**Figure 2-1. YSI 6600 EDS Water Probe**

Building upon the YSI Rapid Pulse™ DO system, the 6600 EDS is maintained free of fouling by the Clean Sweep™ universal wiper assembly, as well as by individual optical wipers. 6600 EDS sensors are field-replaceable and integrate with data collection platforms. Flash memory prevents data loss, and C-cell battery power allows long-term deployment. The tested 6600 EDS was coated with YSI's optional anti-fouling paint.

The range, resolution, and accuracy of the YSI 6600 EDS, as indicated by the vendor, are listed below for the parameters tested.

| **Parameter** | **Range** | **Resolution** | **Accuracy** |
|---|---|---|---|
| DO % Saturation | 0 to 500% | 0.1% | 0 to 200%: ±2%; 200 to 500%: ±6% of reading |
| DO mg/L | 0 to 50 milligrams/liter (mg/L) | 0.01 mg/L | 0 to 20 mg/L: ±0.2 mg/L; 20 to 50 mg/L:±0.6 mg/L |
| Conductivity | 0 to 100 millisiemen (mS)/centimeter (cm) | 0.001 to 0.1 mS/cm | ±0.5% of reading +0.001 mS/cm |
| Temperature | -5 to +45˚C | 0.01˚C | ±0.15˚C |
| pH | 0 to 14 | 0.01 | ±0.2 |

| | | | |
|---|---|---|---|
| Turbidity | 0 to 1,000 nephelometric turbidity unit (NTU) | 0.1 NTU | ±5% of reading or 2 NTU, whichever is greater |
| Chlorophyll | 0 to 400 microgram (µg)/L<br>0 to 100% fluorescence | 0.1 µg/L chlorophyll;<br>0.1% fluorescence | |

The outer diameter of the 6600 EDS is 8.9 cm (3.5 inches). It is 52 cm (20.4 inches) long and weighs 2.7 kilograms (six pounds).

# Chapter 3
# Test Design and Procedures

## 3.1 Introduction

This verification test was conducted according to procedures specified in the *Test/QA Plan for Long-Term Deployment of Multi-Parameter Water Quality Probes/Sondes*.[1] The purpose of the verification test was to evaluate the performance of the 6600 EDS under realistic operating conditions. The 6600 EDS was evaluated by comparing pre- and post-calibration results and their measurements with standard reference measurements and handheld calibrated probes. Two 6600 EDSs were deployed in saltwater, freshwater, and laboratory environments near Charleston, South Carolina, during a 2 ½-month verification test. Water quality parameters were measured both by the 6600 EDSs and by reference measurements consisting of both field-portable instrumentation and water analyses of collected samples. During each phase, performance was assessed in terms of pre- and post-calibration results, relative bias, precision, linearity, and inter-unit reproducibility for each 6600 EDS.

The 6600 EDSs were verified in terms of its performance on the following parameters:

- DO
- Conductivity
- Temperature
- pH
- Turbidity
- Chlorophyll.

## 3.2 Test Site Characteristics

The three test sites used for this verification were selected in an attempt to expose the 6600 EDSs to the widest possible range of conditions while conducting an efficient test. The three sites included one saltwater, one freshwater, and one controlled location. Approximate ranges for the target parameters at each of the test sites as determined by reference measurements are given in Table 3-1.

**Table 3-1. Water Characteristics at the Test Sites**

| Parameter | Saltwater Low | Saltwater High | Freshwater Low | Freshwater High | Mesocosm Low | Mesocosm High |
|---|---|---|---|---|---|---|
| DO | 3 mg/L | 7.3 mg/L | 1.2 mg/L | 13.4 mg/L | 3.7 mg/L | 7.3 mg/L |
| Conductivity | 20 mS/cm | 40 mS/cm | 0.2 mS/cm | 0.45 mS/cm | 0.5 mS/cm | 38 mS/cm |
| Temperature | 28°C | 32°C | 20°C | 35°C | 24°C | 31°C |
| pH | 7 | 8 | 6 | 9 | 7.3 | 8.5 |
| Turbidity | 3 NTU | 11 NTU | 0.1 NTU | 20 NTU | 0.1 NTU | 130 NTU |
| Chlorophyll (total fluorescence) | 1 µg/L | 5 µg/L | 0.5 µg/L | 60 µg/L | 1 µg/L | 50 µg/L |

### 3.3 Test Design

The verification test was designed to assess the performance of multi-parameter water probes and was closely coordinated with the National Oceanic and Atmospheric Administration (NOAA) through the CCEHBR. The test was conducted in three phases at a saltwater site in the Cooper River; a freshwater site at Lake Edmunds, approximately one mile from the Center for Coastal Environmental Health and Biomolecular Research (CCEHBR); and a controlled site at the CCEHBR mesocosm facility in Charleston, South Carolina. The first phase of the test was conducted at the saltwater site and lasted 31 days. The CCEHBR campus has access to the Charleston Harbor Estuary, which is a predominantly tidal body of water that receives some riverine input; its salinities range from 20 to 35 parts per thousand. Figure 3-1 shows the saltwater site at the Cooper River. The second phase of the test was conducted at the freshwater site and lasted 24 days. The freshwater site was at a five-acre lake, named Lake Edmunds, approximately one mile from the CCEHBR facility. Figure 3-2 shows the freshwater site. The third phase was conducted over seven days at the the CCEHBR's mesocosm facility. This facility contains modular mesocosms that can be classified as "tidal" or "estuarine." Figure 3-3 shows one of the modular mesocosms. At each test site, two 6600 EDSs were deployed as close to each other as possible to assess inter-unit reproducibility.

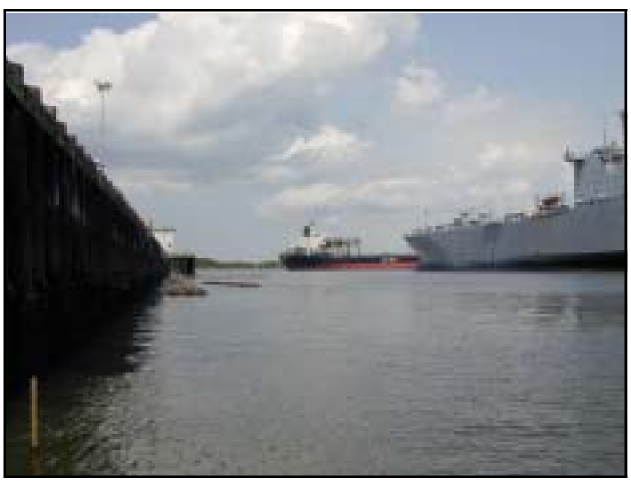


**Figure 3-1. Saltwater Site**

The schedule for the various testing activities is given in Table 3-2. The saltwater tests began in a small tidal creek tributary of the Charleston Harbor near the CCEHBR facilities. Testing at this location lasted approximately two weeks, but had to be discontinued due to a structural failure of the pier. A new site at NOAA Pier Romeo on the Cooper River was selected to complete the testing. This site is approximately 10 miles from the CCEHBR facility and is operated by NOAA's Coastal Services Center.

**Figure 3-2. Freshwater Site**

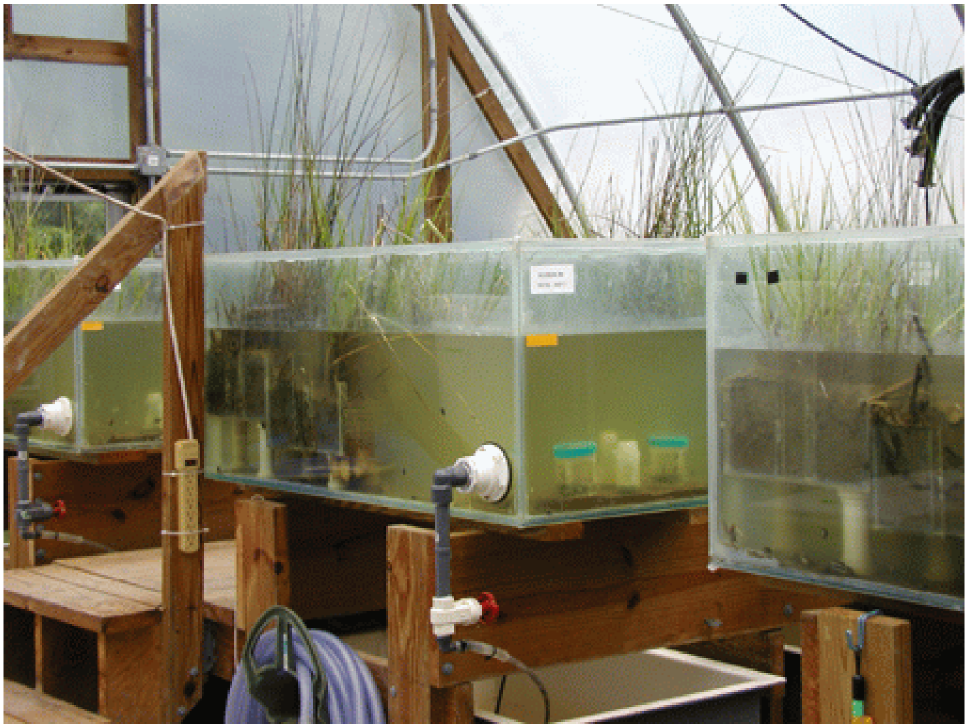


**Figure 3-3. Mesocosm Tank**

**Table 3-2. Schedule for the 6600 EDS Verification Test**

| Activity | Date |
|---|---|
| Vendor setup | June 10 |
| Begin saltwater test at CCEHBR small tidal creek | June 17 |
| End saltwater test at CCEHBR small tidal creek due to structural failure | July 9 |
| Setup at Cooper River (Pier Romeo) | July 11 |
| Begin saltwater test at Charleston Harbor (Pier Romeo) | July 15 |
| End saltwater test | August 14 |
| Set up freshwater test at Lake Edmunds | August 19 |
| Begin freshwater test | August 21 |
| End freshwater test | September 13 |
| Vendor setup for mesocosm test at CCEHBR | September 16 |
| Begin mesocosm test | September 19 |
| End mesocosm test | September 25 |
| Vendor removal of equipment | September 30 |

### *3.3.1 Saltwater Testing*

Saltwater testing was conducted at two locations. The planned location was in the Charleston River near the NOAA CCEHBR facility. However, due to structural problems at that site, the probes were redeployed in the Charleston Harbor to NOAA Pier Romeo. Pre- and post-calibration data obtained at the first location are presented in Section 6.1 of this report; however, no additional data from that location are available.

The saltwater test lasted for 31 days, during which time the 6600 EDSs monitored the naturally occurring range of the target parameters 24 hours a day, while dockside reference measurements were made, and reference samples for turbidity and chlorophyll were collected. The 6600 EDSs were mounted on iron posts that were driven into the river bed. The instruments were approximately 0.5 meters apart (Figure 3-4) in the shallows of the Cooper River. Samples were collected in rotation during the morning, afternoon, and evening throughout the test. In addition, more intense sampling occurred at the beginning (Days 1 and 2) and the end (Days 29 and 30) of the sampling period, when samples were taken at 15- to 30-minute intervals for eight hours, except on Day 29, when only four hours of sampling occurred because of weather conditions. For the duration of the test, the 6600 EDSs were deployed at depths between approximately three and 10 feet, varying according to the tide. Table 3-3 shows the times and numbers of samples taken throughout the saltwater test period. Aside from the initial setup days (July 11 through 14), the 6600 EDSs were deployed at Pier Romeo and collecting data approximately every 15 minutes on the days indicated in Table 3-3.

**Figure 3-4. Saltwater Deployment**

### *3.3.2 Freshwater Testing*

Freshwater testing was conducted at Lake Edmunds. Because this site is shallower than Charleston Harbor, samples were taken at only one depth (approximately 0.3 meters). As in the saltwater portion of the verification test, the 6600 EDSs monitored the naturally occurring target parameters 24 hours a day, while reference measurements were made and turbidity and chlorophyll reference samples collected, again rotating among collection times. More intense sampling occurred at the beginning (Day 3) and the end (Day 23) of the sampling period, when samples were taken at 15- to 30-minute intervals for periods ranging between six and eight hours, as weather permitted. Table 3-4 shows the sampling times and number of samples collected throughout the freshwater test period. The 6600 EDSs were tethered with cable ties to large posts driven into the bottom of the lake.

### *3.3.3 Mesocosm Testing*

Mesocosm testing was performed according to the schedule shown in Table 3-5. The mesocosm tanks were filled with water and drained twice daily, simulating a semi-diurnal tidal cycle. Reference measurements were made and water samples were collected during each test day throughout the normal operating hours of the facility (nominally 6 a.m. to 6 p.m.). During this period, the mesocosm was manipulated to introduce variations in the measured parameters. The turbidity of the system was varied by operating a pump near the sediment trays to suspend additional solids in the water. Conductivity was varied by adding freshwater to the saltwater during one of the fill-and-drain cycles.

## Table 3-3. Schedule for Saltwater Sample Collection

| Test Day | Day of Week | Date | # Reference Samples | # Field Blanks | # Duplicate Samples | Location |
|---|---|---|---|---|---|---|
| Initial setup | Thu | 11-Jul-02 | | | | Pier Romeo |
| | Fri | 12-Jul-02 | | | | Pier Romeo |
| | Sat | 13-Jul-02 | | | | Pier Romeo |
| | Sun | 14-Jul-02 | | | | Pier Romeo |
| 1 | Mon | 15-Jul-02 | 16 | | | Pier Romeo |
| 2 | Tue | 16-Jul-02 | 16 | | | Pier Romeo |
| 3 | Wed | 17-Jul-02 | 3 | 1 | 1 | Pier Romeo |
| 4 | Thu | 18-Jul-02 | | | | Laboratory |
| 5 | Fri | 19-Jul-02 | | | | Laboratory |
| 6 | Sat | 20-Jul-02 | | | | Pier Romeo |
| 7 | Sun | 21-Jul-02 | | | | Pier Romeo |
| 8 | Mon | 22-Jul-02 | 2 | | | Pier Romeo |
| 9 | Tue | 23-Jul-02 | | | | Pier Romeo |
| 10 | Wed | 24-Jul-02 | 3 | 1 | 1 | Pier Romeo |
| 11 | Thu | 25-July-02 | 2 | 1 | | Pier Romeo |
| 12 | Fri | 26-Jul-02 | | | | Laboratory |
| 13 | Sat | 27-Jul-02 | | | | Laboratory |
| 14 | Sun | 28-Jul-02 | | | | Laboratory |
| 15 | Mon | 29-Jul-02 | | | | Laboratory |
| 16 | Tue | 30-Jul-02 | | | | Laboratory |
| 17 | Wed | 31-Jul-02 | | | | Laboratory |
| 18 | Thu | 01-Aug-02 | | | | Laboratory |
| 19 | Fri | 02-Aug-02 | | 1 | 1 | Pier Romeo |
| 20 | Sat | 03-Aug-02 | | | | Pier Romeo |
| 21 | Sun | 04-Aug-02 | | | | Pier Romeo |
| 22 | Mon | 05-Aug-02 | | 1 | 1 | Pier Romeo |
| 23 | Tue | 06-Aug-02 | 2 | 2 | 1 | Pier Romeo |
| 24 | Wed | 07-Aug-02 | 3 | 1 | 1 | Pier Romeo |
| 25 | Thu | 08-Aug-02 | | | | Pier Romeo |
| 26 | Fri | 09-Aug-02 | | | | Pier Romeo |
| 27 | Sat | 10-Aug-02 | | | | Pier Romeo |
| 28 | Sun | 11-Aug-02 | | | | Pier Romeo |
| 29 | Mon | 12-Aug-02 | 7 | | | Pier Romeo |
| 30 | Tue | 13-Aug-02 | 16 | | | Pier Romeo |
| 31 | Wed | 14-Aug-02 | | | | Pier Romeo |

**Table 3-4. Schedule for Freshwater Sample Collection**

| Test Day | Day of Week | Date | # Reference Samples | # Field Blanks | # Duplicate Samples | Location |
|---|---|---|---|---|---|---|
| | Mon | 19-Aug-02 | | | | Laboratory |
| | Tue | 20-Aug-02 | | | | Laboratory |
| 1 | Wed | 21-Aug-02 | | | | Lake Edmunds |
| 2 | Thu | 22-Aug-02 | | | | Lake Edmunds |
| 3 | Fri | 23-Aug-02 | 16 | | | Lake Edmunds |
| 4 | Sat | 24-Aug-02 | | | | Lake Edmunds |
| 5 | Sun | 25-Aug-02 | | | | Lake Edmunds |
| 6 | Mon | 26-Aug-02 | 4 | | | Lake Edmunds |
| 7 | Tue | 27-Aug-02 | | | | Lake Edmunds |
| 8 | Wed | 28-Aug-02 | 2 | 1 | 1 | Lake Edmunds |
| 9 | Thu | 29-Aug-02 | | | | Laboratory |
| 10 | Fri | 30-Aug-02 | | | | Laboratory |
| 11 | Sat | 31-Aug-02 | | | | Lake Edmunds |
| 12 | Sun | 01-Sep-02 | | | | Lake Edmunds |
| 13 | Mon | 02-Sep-02 | | | | Lake Edmunds |
| 14 | Tue | 03-Sep-02 | | | | Lake Edmunds |
| 15 | Wed | 04-Sep-02 | | 1 | 1 | Lake Edmunds |
| 16 | Thu | 05-Sep-02 | 2 | 1 | 1 | Laboratory |
| 17 | Fri | 06-Sep-02 | | | | Laboratory |
| 18 | Sat | 07-Sep-02 | | | | Laboratory |
| 19 | Sun | 08-Sep-02 | | | | Lake Edmunds |
| 20 | Mon | 09-Sep-02 | 3 | | 1 | Lake Edmunds |
| 21 | Tue | 10-Sep-02 | 3 | 1 | | Lake Edmunds |
| 22 | Wed | 11-Sep-02 | | | | Lake Edmunds |
| 23 | Thu | 12-Sep-02 | 12 | | | Lake Edmunds |
| 24 | Fri | 13-Sep-02 | | | | Laboratory |

**Table 3-5. Schedule for Mesocosm Sample Collection**

| Test Day | Day of Week | Date | # Reference Samples | # Field Blanks | # Duplicate Samples | Location |
|---|---|---|---|---|---|---|
| | Mon | 16-Sep-02 | | | | Laboratory |
| | Tue | 17-Sep-02 | | | | Laboratory |
| | Wed | 18-Sep-02 | | | | Laboratory |
| 1 | Thu | 19-Sep-02 | 2 | | | Mesocosm |
| 2 | Fri | 20-Sep-02 | 5[a] | | | Mesocosm |
| 3 | Sat | 21-Sep-02 | | | | Mesocosm |
| 4 | Sun | 22-Sep-02 | | | | Mesocosm |
| 5 | Mon | 23-Sep-02 | 6[b] | | | Mesocosm |
| 6 | Tue | 24-Sep-02 | 6[c,d] | | | Mesocosm |
| 7 | Wed | 25-Sep-02 | 1 | 1 | 1 | Mesocosm |
| | Thu | 26-Sep-02 | | | | Laboratory |
| | Fri | 27-Sep-02 | | | | Laboratory |

(a) Stir sediment.
(b) Turn off aeration pump.
(c) Turn on aeration pump.
(d) Add freshwater.

Variations in temperature, pH, DO, and chlorophyll were driven by natural forces and the changes in the other test parameters. Parameters over the ranges specified in Table 3-1 were monitored by the 6600 EDSs. Each of the collected samples was analyzed using a reference method for comparison.

## 3.4 Materials and Equipment

The reference equipment used in this verification test was selected for the specific parameter, as follows:

- DO—National Institute of Standards and Technology (NIST)-traceable, commercially available probe (Orion 830A)
- Conductivity—NIST-traceable, handheld conductivity meter (Oakton 35631-00)
- Temperature—NIST-traceable, handheld thermocouple and readout (Orion 830A)
- pH—NIST-traceable, handheld pH meter (Oakton 35631-00)

- Turbidity—Hach Ratio XR turbidity meter (Hach 43900)

- Chlorophyll—Turner 10-AU fluorometer (total in vivo fluorescence).

Reagents were distilled deionized water (for field blanks) and a Hach Ratio XR turbidity standard from Advanced Polymer Systems. Sampling equipment consisted of 0.5- to 1.0-L glass bottles, a Niskin sampling device provided by CCEHBR, and provisions for sample storage. The maximum sample holding times are given in Table 3-6. All sample holding time requirements were met.

**Table 3-6. Maximum Sample Holding Times**

| Parameter | Holding Time |
|---|---|
| DO | none[a] |
| Conductivity | none |
| Temperature | none |
| pH | none |
| Turbidity | 24 hours |
| Chlorophyll | 1 week |

[a] “None” indicates that the sample analyses must be performed immediately after sample collection or in the water column at the site.

# Chapter 4
# Quality Assurance/Quality Control

Quality assurance/quality control (QA/QC) procedures were performed in accordance with the quality management plan (QMP) for the AMS Center(2) and the test/QA plan for this verification test.(1)

## 4.1 Instrument Calibration

Both the portable and laboratory reference instruments were calibrated by CCEHBR according to the procedures and schedules in place at the test facility, and documentation was provided to Battelle.

## 4.2 Field Quality Control

Field blanks and laboratory duplicate samples were taken at the times shown in Tables 3-3 through 3-5. The field blank was a container of deionized water taken to the field and then brought back to the laboratory. It was analyzed in the same manner as the collected samples. The laboratory replicate samples were collected once each week during a regular sampling period. These replicate samples were the field sample split in the field into two separate samples (containers) and analyzed by the same methods. The results from the replicate analysis were within the expected values shown in Table 4-1. The results for the field blanks were within the expected tolerances.

## 4.3 Sample Custody

Samples collected at the saltwater and freshwater sites were transported by CCEHBR to the laboratory in an ice-filled cooler.

**Table 4-1. Replicate Analysis Results**

| Parameter | Anticipated Interval of Results |
|---|---|
| DO | ±5% |
| Conductivity | ±5% |
| Temperature | ±1°C |
| pH | ±0.1 |
| Turbidity | ±5 NTU |
| Chlorophyll | ±5% |

**Table 4-2. Expected Values for Field Blanks**

| Parameter | Expected Maximum Value |
|---|---|
| Turbidity | 1 NTU |
| Chlorophyll | 3 x average of three blank filters |

## 4.4 Audits

### *4.4.1 Performance Evaluation Audit*

A performance evaluation (PE) audit was conducted by the Battelle Test Coordinator once during the verification test to assess the quality of the reference measurements. For the PE audit, independent standards were used. Table 4-3 shows the procedures used for the PE audit and associated results.

**Table 4-3. Summary of Performance Evaluation Audits**

| Audited Parameter | Audit Procedure | Acceptable Tolerance | Actual Difference | Passed Audit |
|---|---|---|---|---|
| DO | Independent monitor | ±5% | 6.7% | No[a] |
| Conductivity | Independent monitor | ±5% | 0.6% | Yes |
| Temperature | Independent monitor | ±1°C | 0.2°C | Yes |
| pH | Independent monitor | ±0.1 pH | 0.04 pH | Yes |
| Turbidity | Independent turbidity standard | ±10% | 0.4% | Yes |
| Chlorophyll | Independent chlorophyll standard | ±5% | 0.4% | Yes |

[a] Although the measurement recorded during the PE audit was outside the acceptable tolerance, this measurement was repeated 111 times during the verification test. The average agreement during the verification test was 0.2%; therefore, no corrective action was taken.

The DO measurement made by the Orion 830A was compared with that from a handheld DO monitor made by Hanna (94130M). Agreement within 6.7% was achieved. Although this measurement was outside the acceptable tolerance, the measurement was, in fact, repeated 111 times during the verification test, with an average difference of 0.2%, indicating acceptable performance of the reference monitor. A handheld conductivity meter made by Hanna (H19835) was used to perform the conductivity audit. Agreement within 0.6% between the results of the Hanna meter and those of the Oakton reference meter was seen. A NIST-traceable mercury-in-glass thermometer was used for the temperature performance audit. The comparison was made with a sample of collected water, and agreement was within 0.2°C. The handheld pH reference meter from Oakton was compared with a handheld pH meter made by Hanna (991301). A pH tolerance of 0.04% was recorded. The Hach turbidity meter measurements were compared with an independent turbidity standard. Agreement within 0.4% was observed.

### *4.4.2 Technical Systems Audit*

The Battelle Quality Manager conducted a technical systems audit (TSA) on August 28, 2002, to ensure that the verification test was performed in accordance with the test/QA plan[1] and the AMS Center QMP.[2] As part of the audit, the Battelle Quality Manager reviewed the reference methods used, compared actual test procedures to those specified in the test/QA plan, and reviewed data acquisition and handling procedures. Observations and findings from this audit were documented and submitted to the Battelle Verification Test Coordinator for response. No findings were documented that required any corrective action. The records concerning the TSA are permanently stored with the Battelle Quality Manager.

During the verification test, three deviations from the test/QA plan were necessary. The first was because the manufacturer’s instructions required a different calibration frequency than the test/QA plan for pH, conductivity, and turbidity measurements. Because the calibrations were within the specified range during each calibration, it was determined that there was no impact on the verification test. The second and third deviations were that the sampling frequency and total number of samples were different than stated in the test/QA plan. Samples were taken at 15- instead of 30-minute intervals because, in some cases, sampling went faster than anticipated; and weather and environmental conditions required ending the deployment sooner than specified by the test/QA plan, resulting in fewer samples.

### *4.4.3 Audit of Data Quality*

At least 10% of the data acquired during the verification test were audited. Battelle’s Quality Manager traced the data from the initial acquisition, through reduction and statistical analysis, to final reporting, to ensure the integrity of the reported results. All calculations performed on the data undergoing the audit were checked.

## 4.5 QA/QC Reporting

Each assessment and audit was documented in accordance with Sections 3.3.4 and 3.3.5 of the QMP for the ETV AMS Center.[2] Once the assessment report was prepared, the Verification

Test Coordinator ensured that a response was provided for each adverse finding or potential problem and implemented any necessary follow-up corrective action. The Battelle Quality Manager ensured that follow-up corrective action was taken. The results of the TSA were sent to the EPA.

### 4.6 Data Review

Records generated in the verification test were reviewed within two weeks of generation before these records were used to calculate, evaluate, or report verification results. Table 4-4 summarizes the types of data recorded. The review was performed by a Battelle technical staff member involved in the verification test, but not the staff member who originally generated the record. The person performing the review added his/her initials and the date to a hard copy of the record being reviewed.

**Table 4-4. Summary of Data Recording Process**

| Data to be Recorded | Responsible Party | Where Recorded | How Often Recorded | Disposition of Data |
|---|---|---|---|---|
| Dates, times of test events | CCEHBR | Laboratory record books/data sheets | Start/end of test; at each change of a test parameter; at sample collection | Used to organize/ check test results; manually incorporated data into spreadsheets - stored in study binder |
| Test parameters | Battelle/ CCHEBR | Laboratory record books/ data sheets | Each sample collection | Used to organize/ check test results; manually incorporated data into spreadsheets - stored in study binder |
| 6600 EDS data<br>- digital display<br>- electronic output | <br>CCEHBR<br>CCEHBR | <br>Data sheets<br>Probe data acquisition system (DAS); data stored on probe down-loaded to PC | <br>Continuous<br>15-minute sampling; data downloaded to PC | Used to organize/ check test results; incorporated data into electronic spread-sheets - stored in study binder |
| Reference monitor readings/reference analytical results | CCEHBR | Laboratory record book/ data sheets or data manage-ment system, as appropriate | After each batch sample collection; data recorded after reference method performed | Used to organize/ check test results; manually incorporated data into spreadsheets - stored in study binder |
| Reference calibration data | CCEHBR | Laboratory record books/ data sheets/DAS | Whenever zero and calibration checks are done | Documented correct performance of reference methods |
| PE audit results | Battelle | Laboratory record books/ data sheets/DAS | At times of PE audits | Test reference methods with independent standards/ measurements |

# Chapter 5
# Statistical Methods

The statistical methods presented in this chapter were used to verify the performance parameters listed in Section 3.1.

## 5.1 Pre- and Post-Calibration Results

Pre- and post-calibration of the 6600 EDSs was done for each measured parameter according to that vendor's instruction manual. The results from the calibration checks were summarized, and accuracy was determined each time the calibration check was conducted. Calibration check accuracy ($A$) is reported as a percentage, calculated using the following equation:

$$A=1-(C_s-C_p)/C_s \times 100 \tag{1}$$

Where $C_s$ is the value of the reference standard, and $C_p$ is the value measured by the 6600 EDSs.

## 5.2 Relative Bias

Water samples were analyzed by both the reference method and the 6600 EDSs, and the results were compared. The results for each sample were recorded, and the accuracy was expressed in terms of the average relative bias ($B$), as calculated from the following equation:

$$B=\frac{C_s-C_p}{C_s}\times 100 \tag{2}$$

where $C_P$ is a measurement taken from the 6600 EDS being verified at the same time as the reference measurement was taken, and $C_S$ is the reference measurement. This calculation was performed for each reference sample analysis for each of the six target water parameters. Readings of pH were converted to $H^+$ concentration, and temperature readings were converted to absolute units (i.e., Kelvin) prior to making this calculation. Relative bias was assessed independently for each 6600 EDS to determine inter-unit reproducibility.

### 5.3 Precision

The standard deviation (*S*) of the measurements made during a period of stable operation at the mesocosm was calculated and used as a measure of probe precision:

$$S = \left[ \frac{1}{n-1} \sum_{k=1}^{n} (C_k - \overline{C})^2 \right]^{1/2} \tag{3}$$

where *n* is the number of replicate measurements, $C_k$ is the concentration reported for the k$^{th}$ measurement, and $\overline{C}$ is the average concentration of the replicate measurements.

Precision was calculated for each of the six target water parameters. Probe precision was reported in terms of the percent relative standard deviation (RSD) of the series of measurements.

$$\%RSD = \frac{S}{\overline{C}} * 100 \tag{4}$$

### 5.4 Linearity

For target water parameters with a wide range of variation, linearity was assessed by linear regression, with the analyte concentration measured by the reference method as an independent variable and the reading from the analyzer verified as a dependent variable. Linearity is expressed in terms of the slope, intercept, and coefficient of determination ($r^2$). Linearity for pH was assessed by converting pH results to $H^+$ concentration before comparison. Linearity was assessed separately for each 6600 EDS and for the data generated at each of the saltwater, freshwater, and mesocosm test sites.

### 5.5 Inter-Unit Reproducibility

The results obtained from the two 6600 EDSs were compiled independently for each analyzer and compared to assess inter-unit reproducibility. Inter-unit reproducibility was determined by calculating the average absolute difference between the two 6600 EDSs. In addition, the two 6600 EDSs were compared by evaluating the relative bias of each.

# Chapter 6
# Test Results

The results of the verification of the two 6600 EDSs (identified as YSI AA and YSI AB in this report) are presented in this section. The 6600 EDS data were recorded at 15-minute intervals throughout the verification test. Figures 6-1a through f show plots of nearly 6,000 data points that were collected by the 6600 EDSs during this verification test and data points for the 132 reference samples that were collected and analyzed. (Figures 6-4 through 6-9 show parameter-specific data for each of the three testing periods, so much of the same data is presented as in Figures 6-1a through f, but over a shorter time period and with better resolution.) There were several periods where the 6600 EDSs were not working properly, therefore affecting their measurements. Between June 24, 2002, and August 4, 2002, the conductivity sensor on YSI AA malfunctioned with water leakage into the sensor. The DO sensor on YSI AA was punctured while deployed (possibly by a small marine animal) between June 30, 2002, and July 26, 2002. Finally, the chlorophyll sensors on units YSI AA and AB were improperly replaced by the test operator, which caused erroneous readings between July 31, 2002, and August 16, 2002. Because the 6600 EDSs produced data that were known to be questionable for the specified reasons cited above, the data for periods during which there were measurement problems were removed from the data set. For completeness, the excluded data are reported in Appendix A and are included in Figures 6-1a through f.

Reference sample results and corresponding 6600 EDS readings are provided in Appendix A.

The entire data set is presented in a graphical format in Figures 6-1a through f to allow several non-quantitative observations. First, a comparison of YSI AA and AB and the reference measurements shows that, for each condition and parameter, the 6600 EDSs generally follow the trend of the reference measurements. A visual inspection of the 6600 EDS data for DO, conductivity, temperature, pH, turbidity, and chlorophyll suggests that they agree with each other and the reference measurements.

The DO measurements (Figure 6-1a) show tidal and daily fluctuations, with the freshwater deployment showing the largest magnitude fluctuations. The conductivity measurements (Figure 6-1b) show that the 6600 EDSs again track the daily fluctuations from the saltwater environment, to the freshwater environment, and back to the mesocosm environment. Figure 6-1b also shows that the mesocosm conductivity measured in the saltwater environment closely agrees with the reference measurement during the transition from saltwater to freshwater on September 24, 2002, and back to saltwater. The temperature (Figure 6-1c) and pH (Figure 6-1d) measurements from the 6600 EDSs are overlaid on their respective charts, and

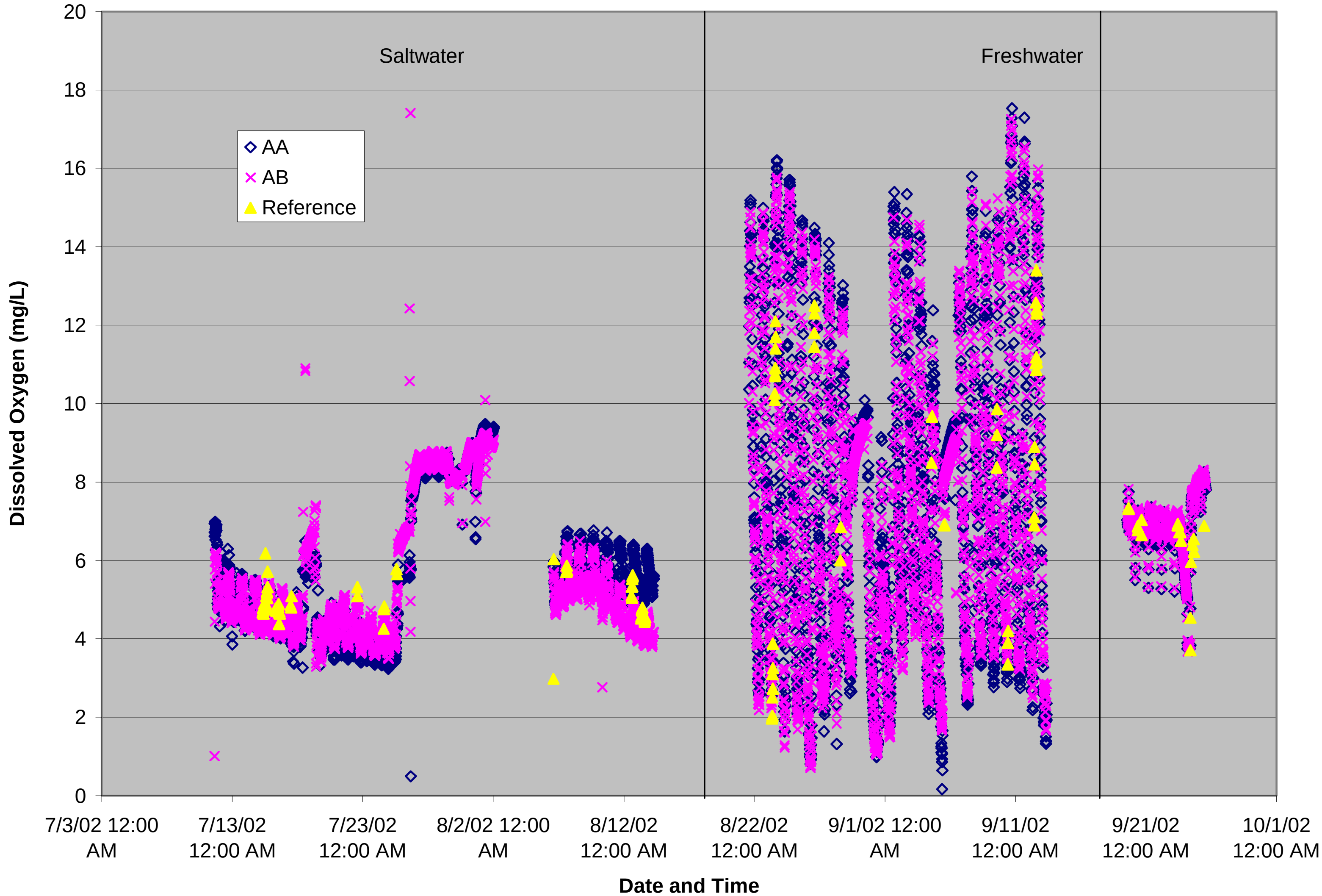



**Figure 6-1a. Dissolved Oxygen Data Collected from YSI AA and YSI AB During the Verification Test**

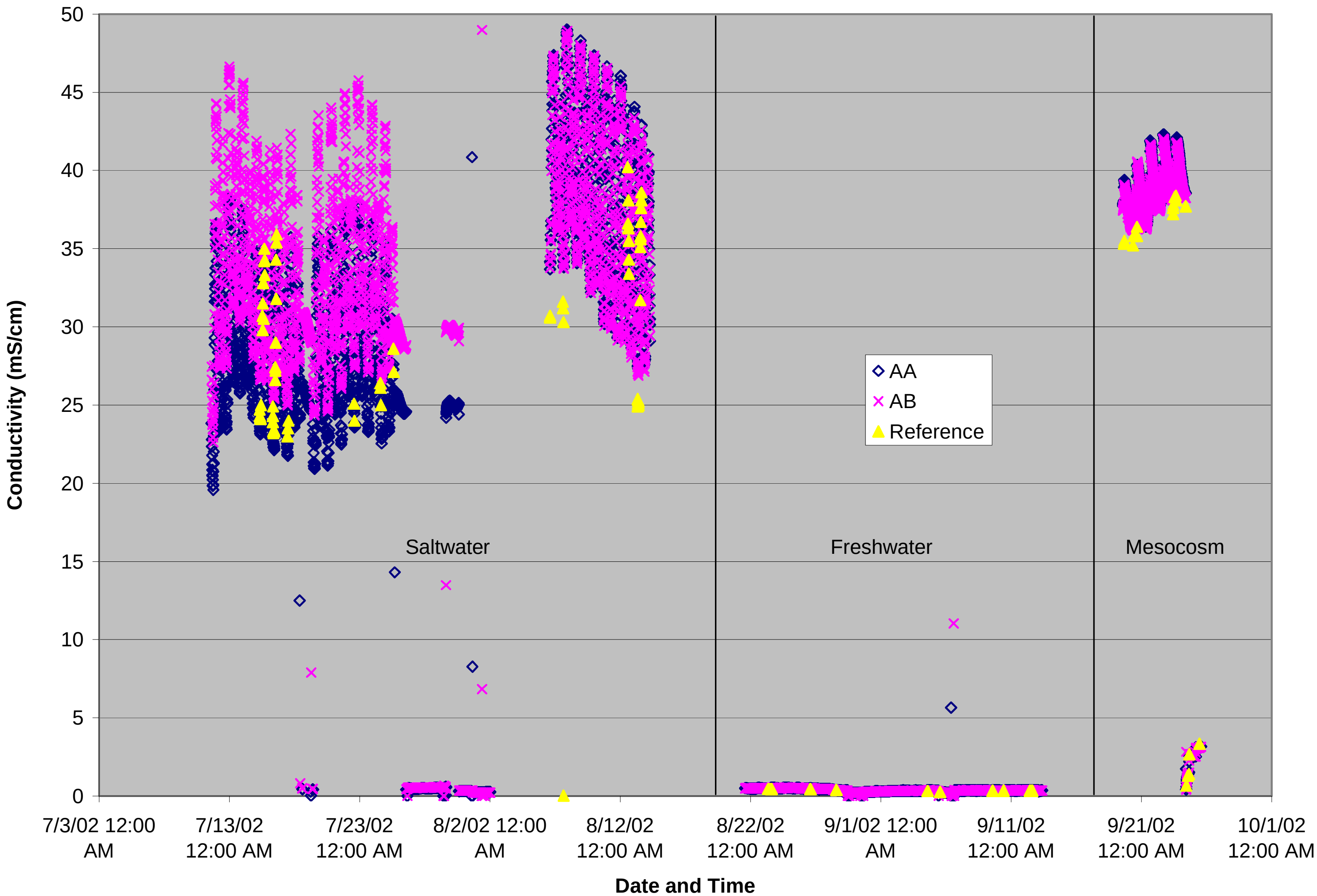



**Figure 6-1b. Conductivity Data Collected from YSI AA and YSI AB During the Verification Test**

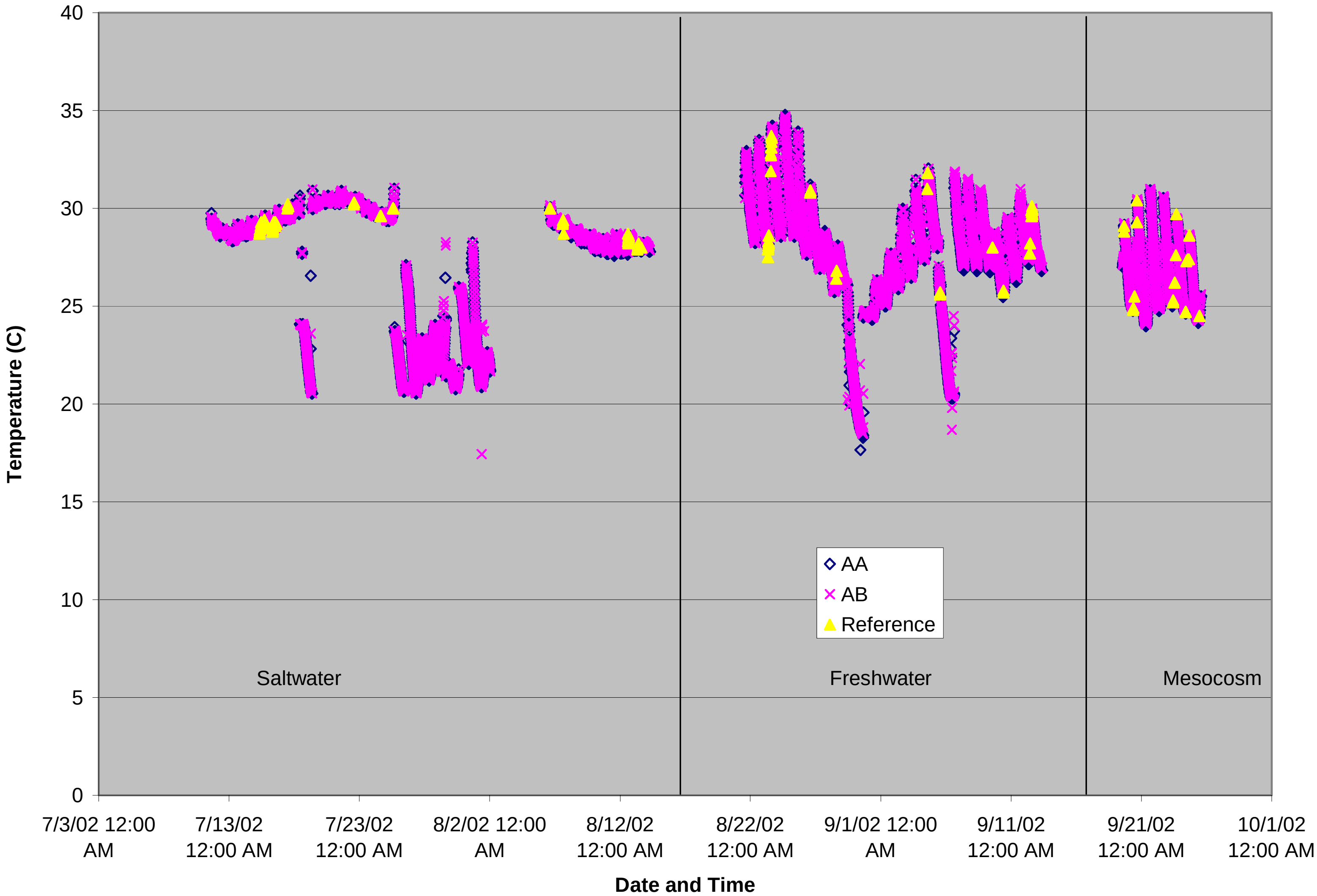



**Figure 6-1c. Temperature Data Collected from YSI AA and YSI AB During the Verification Test**

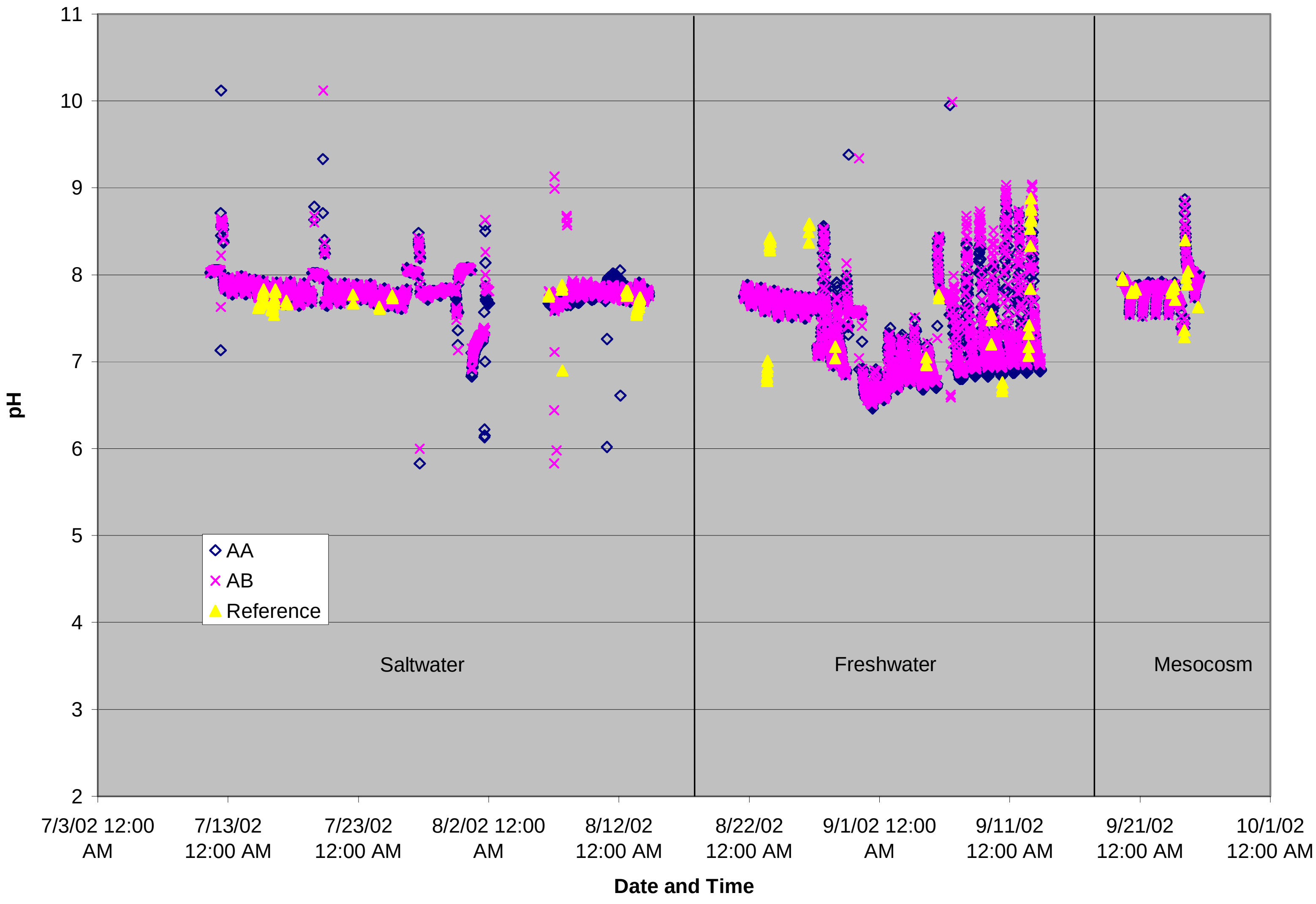



**Figure 6-1d. pH Data Collected from YSI AA and YSI AB During theVerification Test**

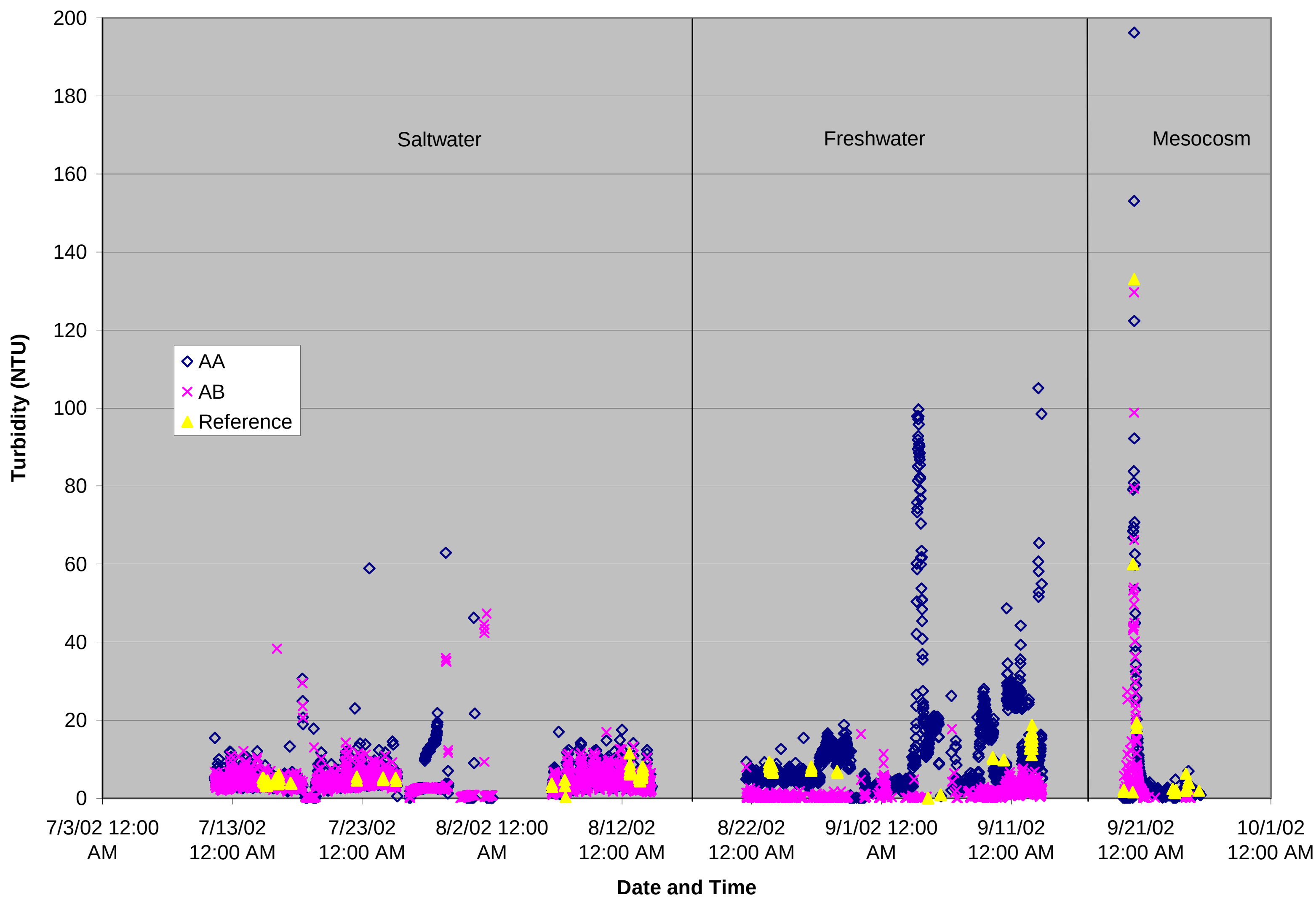



**Figure 6-1e. Turbidity Data Collected from YSI AA and YSI AB During the Verification Test**

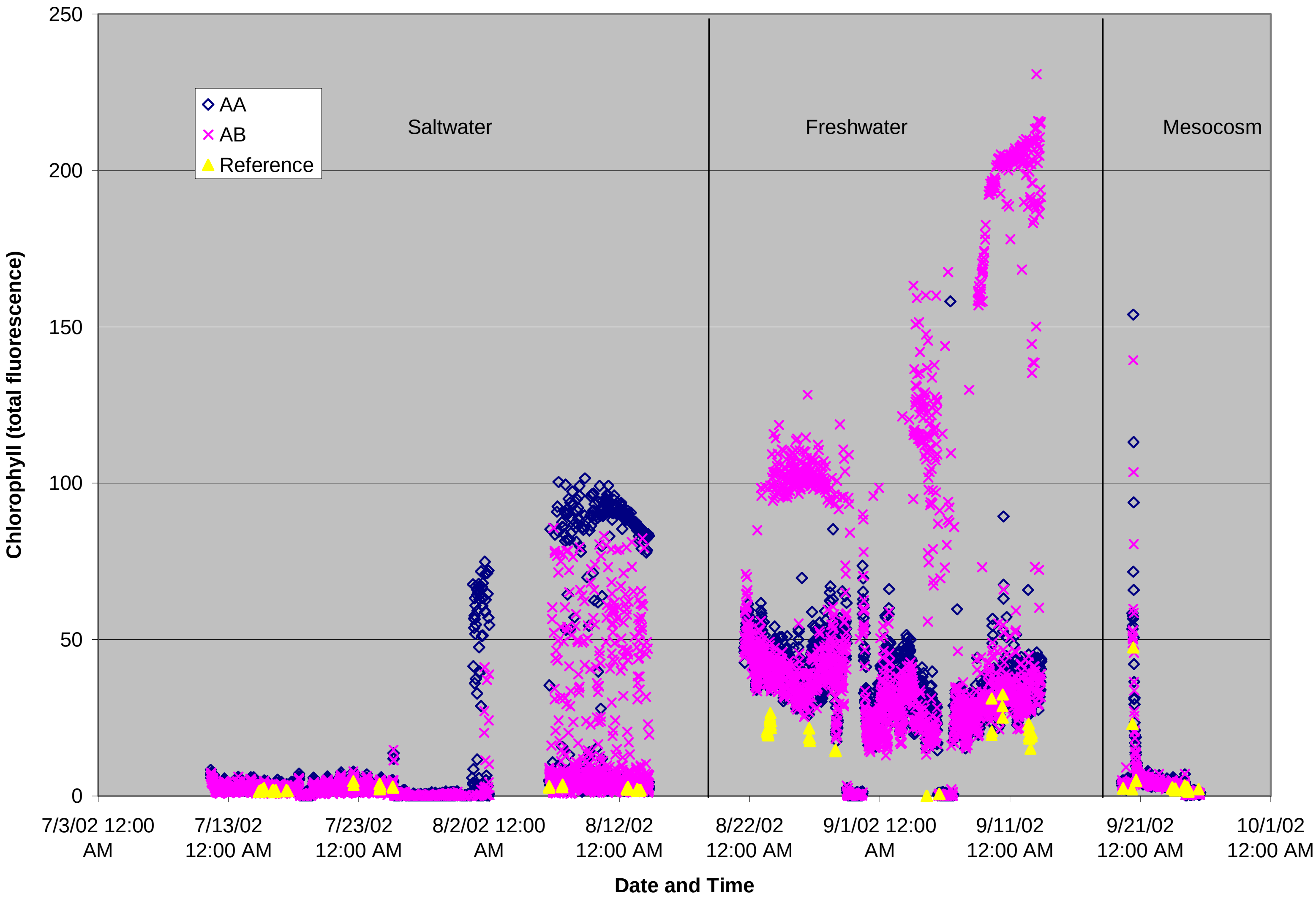



**Figure 6-1f. Chlorophyll Data Collected from YSI AA and YSI AB During the Verification Test**
(A motor malfunction on YSI AB caused erroneous chlorophyll data. The problem was resolved before mesocosm testing.)

their close agreement makes it difficult to see the individual values. Finally, the turbidity (Figure 6-1e) and chlorophyll (Figure 6-1f) measurements made by the 6600 EDSs follow the general trends of the reference measurements and generally agree with each other. It can be seen that, on September 21, 2002, a spike in turbidity and chlorophyll corresponded with the activation of the pump in the mesocosm. This increased level in turbidity and chlorophyll was captured by both YSI AA and AB, as well as the reference measurements. This report attempts to quantify the extent of agreement using the various statistical methods described in Chapter 5.

### 6.1 Pre- and Post-Calibration Results

The 6600 EDSs were calibrated at the beginning and end of each deployment period (noted as "in Laboratory" in Tables 3-3, 3-4, and 3-5). The calibration was checked periodically throughout the deployments to monitor how well the probes held the original calibrations. This operation was performed for pH, conductivity, and DO since only those parameters are adjusted during the calibration. The calibration check levels were selected based on the manufacturer's instructions. Tables 6-1a, b, and c show the results from these calibration checks for the saltwater, freshwater, and mesocosm tests. Figure 6-2 is a graphical representation of these calibration results. The "Reference Standard" column refers to the listed concentration of the standards used in the calibrations, the "YSI AA and YSI AB Readings" columns give the 6600 EDSs results during the calibration checks, and the "YSI AA and YSI AB % Accuracy" columns show the calibration check accuracy using the calculations given in Section 5.1. During the second saltwater deployment, the accuracy for the pH tests ranged from 99% to 102%, for the DO tests from 100% to 109% (except for the very first result of 73%), and for the conductivity tests from 98% to 104%.

## Table 6-1a. Results from Pre- and Post-Calibration Tests for YSI AA and YSI AB in Saltwater[a]

| | Reference Standard | | | YSI AA Readings | | | YSI AB Readings | | | YSI AA % Accuracy | | | YSI AB % Accuracy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | pH[b] | Conductivity (mS/cm) | DO (%) | pH | Conductivity[c] (mS/cm) | DO[d] (%) | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity[e] | DO[e] | pH | Conductivity | DO |
| 6/24/2002 | 7.00 | 50.00 | 100 | 7.04 | – | – | 7.06 | 50.00 | 105.6 | 101 | – | – | 101 | 100 | 106 |
| 6/24/2002 | 10.00 | – | – | 10.09 | – | – | 10.05 | – | – | 101 | – | – | 101 | – | – |
| 7/11/2002 | 7.00 | 50.00 | 100 | 7.08 | – | – | 7.10 | 50.09 | 54.9 | 101 | – | – | 101 | 100 | 55 |
| 7/11/2002 | 10.00 | | | 10.12 | – | – | 10.12 | – | – | 101 | – | – | 101 | – | – |
| 7/19/2002 | 7.00 | 50.00 | 100 | 7.11 | – | – | 7.15 | 48.92 | 73.4 | 102 | – | – | 102 | 98 | 73 |
| 7/19/2002 | 10.00 | – | – | 10.16 | – | – | 10.13 | – | – | 102 | – | – | 101 | – | – |
| 7/29/2002 | 7.00 | 12.88 | 100 | 7.17 | – | – | 7.13 | 12.70 | 100.1 | 102 | – | – | 102 | 99 | 100 |
| 7/29/2002 | 10.00 | – | – | 10.09 | – | – | 10.06 | – | – | 101 | – | – | 101 | – | – |
| 7/31/2002 | 7.00 | 50.00 | 100 | 7.00 | – | – | – | – | – | 100 | – | – | – | – | – |
| 7/31/2002 | 10.00 | – | – | 10.00 | – | – | – | – | – | 100 | – | – | – | – | – |
| 8/1/2002 | 7.00 | 50.00 | 100 | NA | – | – | 7.00 | 50.00 | 100.5 | NA | – | – | 100 | 100 | 101 |
| 8/1/2002 | 10.00 | – | – | NA | – | – | 10.00 | – | – | NA | – | – | 100 | – | – |

[a] Shaded section is from first saltwater deployment.
[b] According to the manufacturer's instructions, the pH calibration checks were performed at two levels, using two separate solutions, while conductivity and DO were checked at one level.
[c] No data taken because of conductivity sensor problem.
[d] No data taken because of punctured membrane.
[e] No calculations performed.
NA = No calibration check was performed on YSI AA on August 1, 2002, because of a problem with the conductivity sensor.

## Table 6-1b. Results from Pre- and Post-Calibration Tests for YSI AA and YSI AB in Freshwater

| Date | Reference Standard | | | YSI AA Reading | | | YSI AB Reading | | | YSI AA % Accuracy | | | YSI AB % Accuracy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity | DO | pH | Conductivity | DO |
| 8/19/2002 | 7.00 | 12.88 | 100 | 7.07 | 12.76 | 100.5 | 7.09 | 12.66 | 100.5 | 101 | 99 | 101 | 101 | 98 | 101 |
| 8/19/2002 | 10.00 | – | – | 10.04 | – | – | 10.04 | – | – | 100 | – | – | – | – | – |
| 8/29/2002 | 7.00 | 1.41 | 100 | 7.01 | 1.42 | 102.3 | 7.00 | 1.42 | 101.3 | 100 | 100 | 102 | 100 | 101 | 101 |
| 8/29/2002 | 10.00 | – | – | 9.94 | – | – | 9.98 | – | – | 99 | – | – | – | – | – |
| 9/6/2002 | 7.00 | 1.41 | 100 | 7.00 | 1.44 | 105.4 | 7.03 | 1.46 | 100.9 | 100 | 102 | 105 | 100 | 104 | 101 |
| 9/6/2002 | 10.00 | – | – | 9.95 | – | – | 9.99 | – | – | 100 | – | – | – | – | – |
| 9/17/2002 | 7.00 | 1.41 | 100 | 7.03 | 1.44 | 108.6 | 7.06 | 1.00 | 101.9 | 100 | 102 | 109 | 101 | 100 | 102 |
| 9/17/2002 | 10.00 | – | – | 9.97 | – | – | – | – | – | 100 | – | – | – | – | – |

**Table 6-1c. Results from Pre- and Post-Calibration Tests for YSI AA and YSI AB in Mesocosm**

| Date | Reference Standard | | | YSI AA Reading | | | YSI AB Reading | | | YSI AA % Accuracy | | | YSI AB % Accuracy | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity (mS/cm) | DO (%) | pH | Conductivity | DO | pH | Conductivity | DO |
| 9/25/2002 | 7.00 | 1.00 | 100 | 7.09 | 1.41 | 99.7 | 7.01 | 1.00 | 101 | 101 | 100 | 100 | 100 | 100 | 101 |
| 9/25/2002 | 10.00 | – | – | 10.02 | – | – | 10.00 | – | – | 100 | – | – | 100 | – | – |

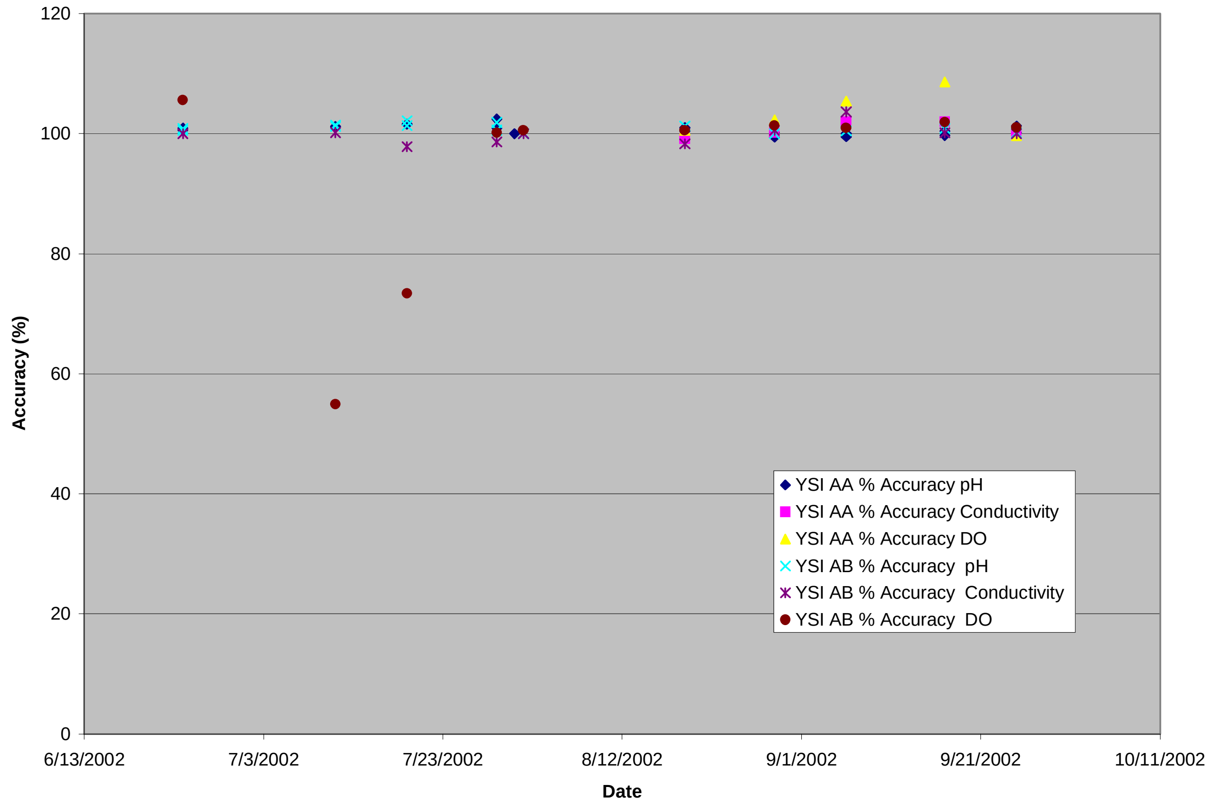
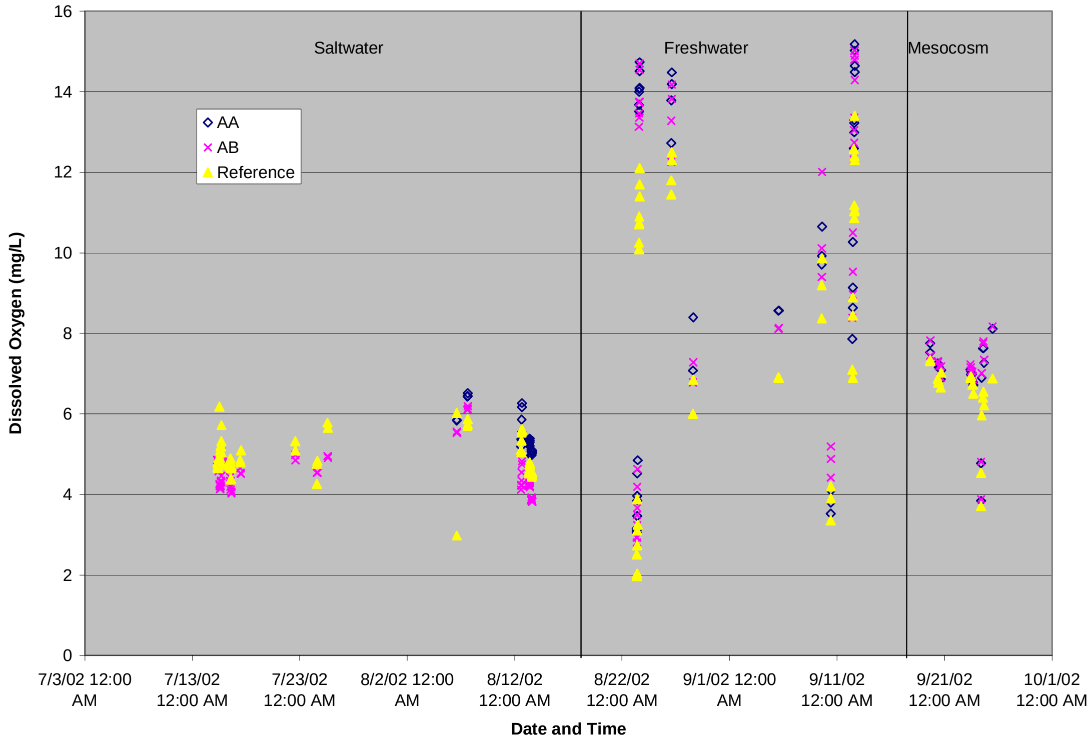



**Figure 6-2. Percent Accuracy of YSI AA and YSI AB During Calibration Checks**

## 6.2 Relative Bias

Relative bias (the percent difference between the 6600EDS measurements and the reference measurements) was assessed by comparing the reference measurements with the YSI AA and YSI AB readings. The reading that correlated most closely in time to the reference sample was used. Plots of the YSI AA and YSI AB data, along with the corresponding reference measurements that were used for the relative bias calculations, are shown in Figures 6-3a through f.

The relative bias is summarized in Table 6-2. The relative bias was less than -28% in saltwater, freshwater, and the mesocosm for the temperature, conductivity, pH, and DO parameters. The bias for temperature was less than 0.1% and for conductivity less than 12%. The DO bias was less than 13.23% at the saltwater site and in the mesocosm, but averaged 22% at the freshwater site. Variability in DO concentration was also greater at the freshwater site, and DO measurements were consistently higher than those reported by the reference unit. The higher DO bias could be, at least in part, a result of the fact that the reference unit (unlike the 6600 EDS) exhibited a large flow dependence, making it necessary to move the sensor rapidly up and down in the water column. This required motion is a possible source of inconsistency in the reference measurement and, since inadequate agitation would result in erroneously low DO values, would explain some (if not all) of the bias in the relative DO readings.




**Figured 6-3a. Relative Bias Data for Dissolved Oxygen**

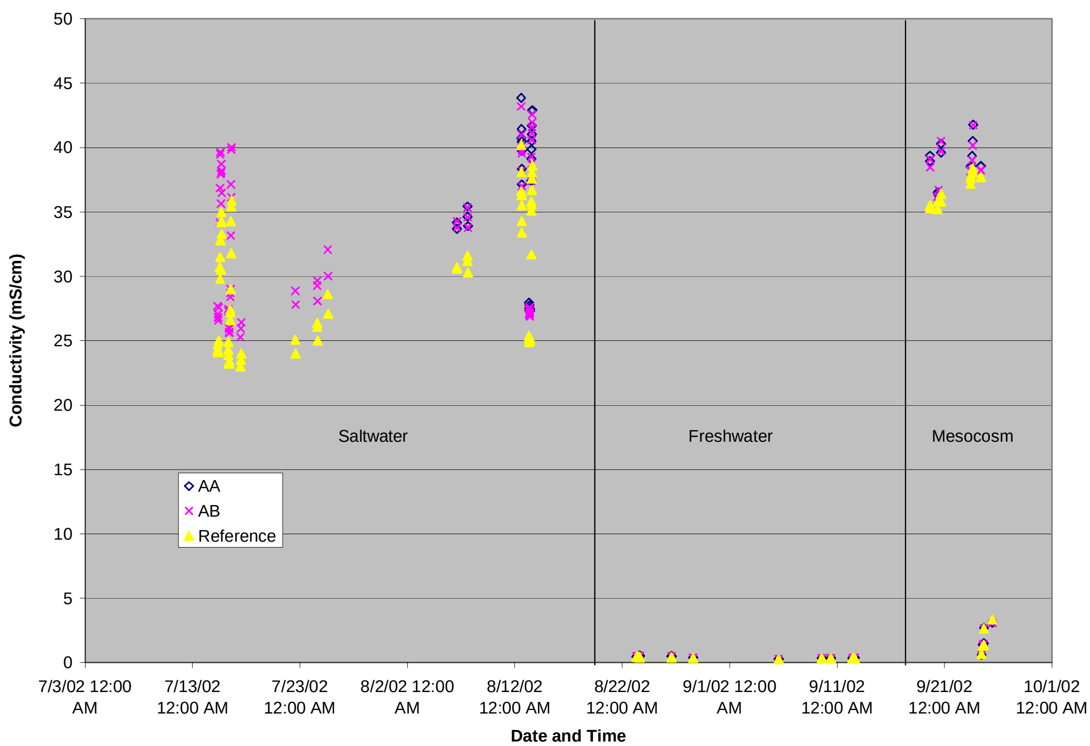



**Figure 6-3b. Relative Bias Data for Conductivity**

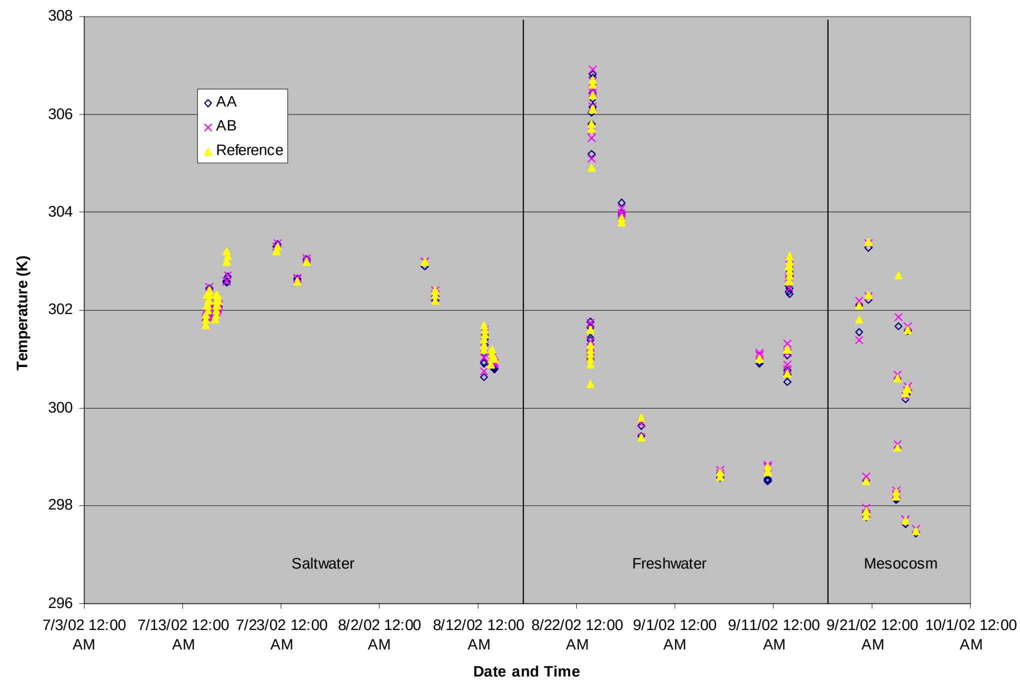



**Figure 6-3c. Relative Bias Data for Temperature**

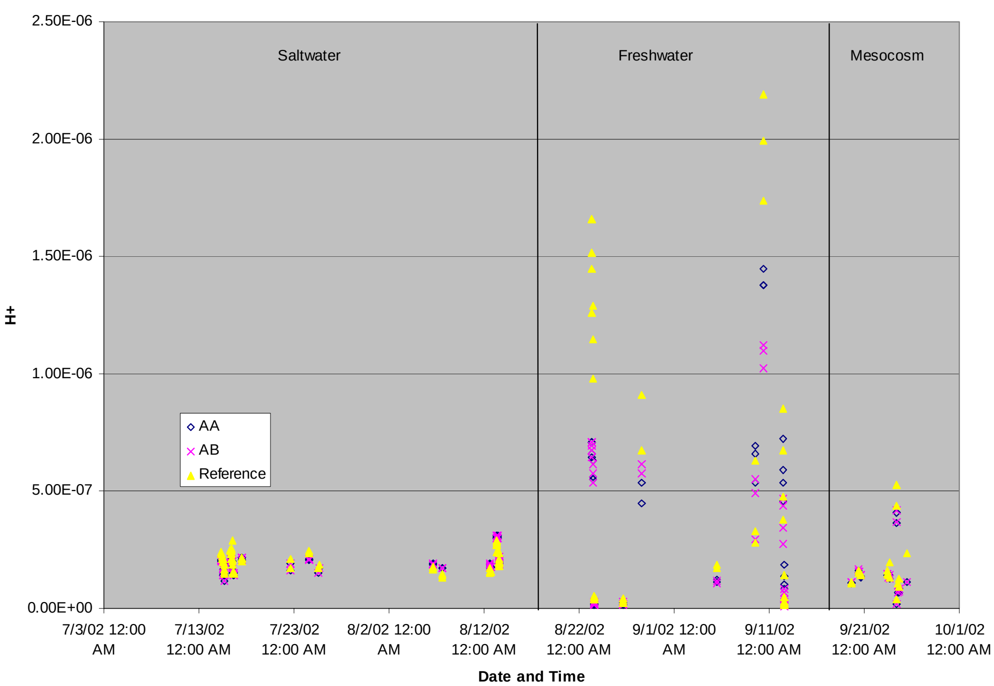



**Figure 6-3d. Relative Bias Data for pH**

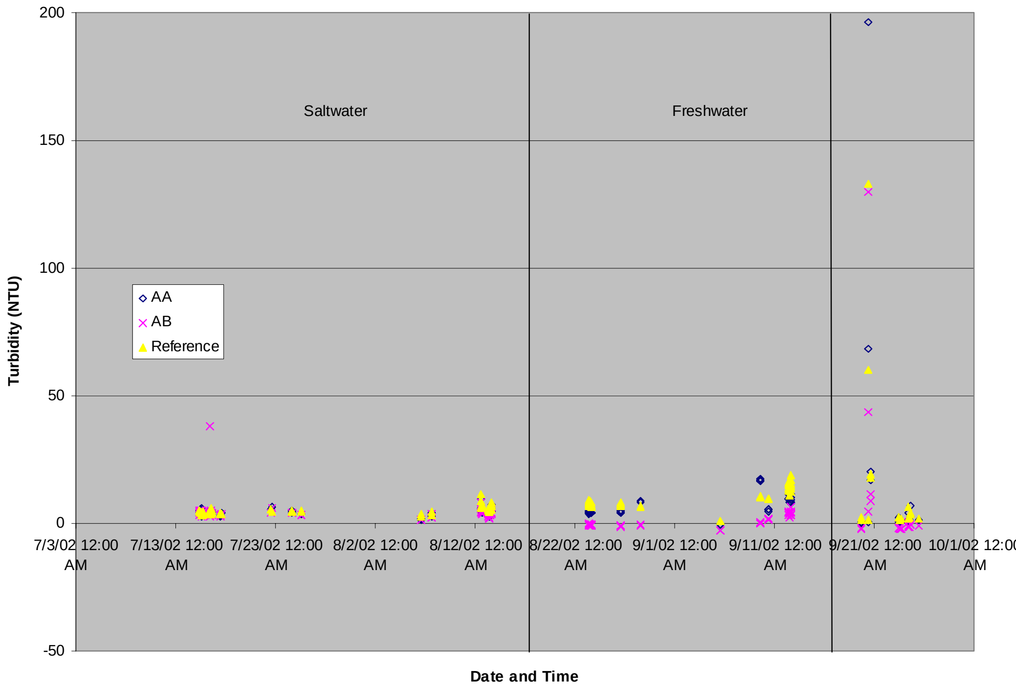



**Figure 6-3e. Relative Bias Data for Turbidity**

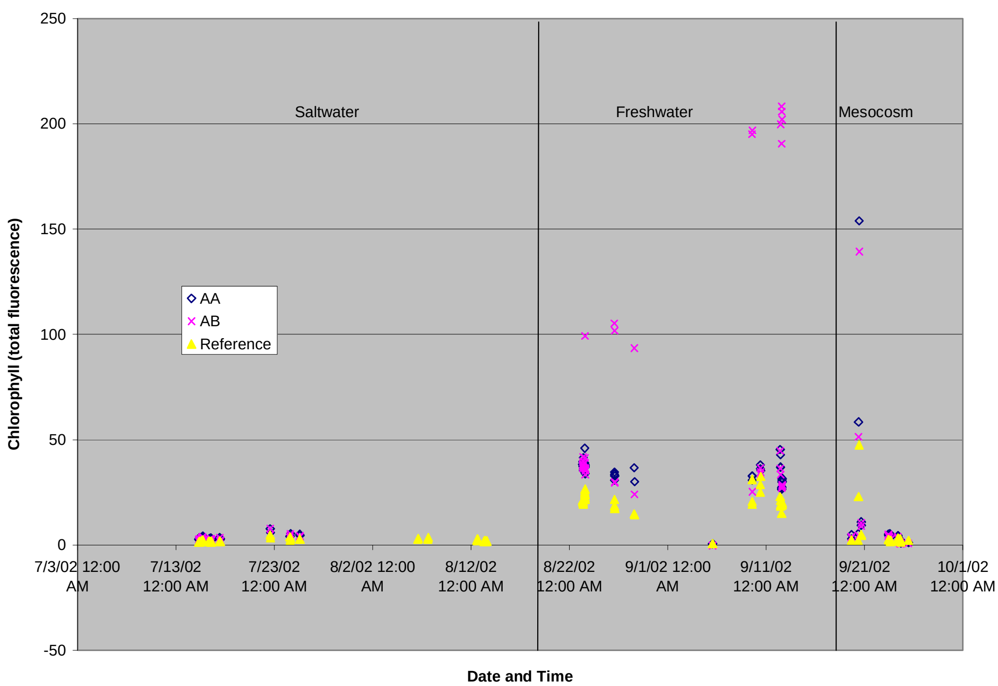



**Figure 6-3f. Relative Bias Data for Chlorophyll** (freshwater data for YSI AB not used)

**Table 6-2. Average Relative Bias Results for YSI AA and YSI AB**

| | | Saltwater | | Freshwater | | Mesocosm | |
|---|---|---|---|---|---|---|---|
| **Parameter** | **Units** | **% Rel. Bias AA** | **% Rel. Bias AB** | **% Rel. Bias AA** | **% Rel. Bias AB** | **% Rel. Bias AA** | **% Rel. Bias AB** |
| Temperature | K | -0.052 | -0.034 | 0.00 | 0.02 | -0.04 | -0.01 |
| Conductivity | mS/cm | 11.08 | 11.4 | 7.70 | 8.77 | 3.91 | 3.00 |
| DO | mg/L | 13.23 | -7.35 | 22.6 | 21.7 | 6.97 | 8.05 |
| H+ | mol/L | -2.79 | -2.79 | 4.80 | -28.0 | -15.9 | -13.2 |
| Turbidity | NTU | -10.9 | -9.54 | -34.1 | -111 | -36.7 | -126 |
| Chlorophyll | total | 74 | 43 | 66.5 | 229 | 75.5 | 46.0 |

The bias for pH was calculated at an average of 28% when using units of mol/L of $H^+$ concentration. However, it should be noted that this bias represents only a difference of approximately 0.10 pH unit between the average 6600 EDS pH values and those of the reference system, which is within the 0.2 pH unit accuracy specification of the system.

As calculated according to Equation 2, the bias for turbidity ranged between -9.54% and 126%. However, it should be noted that, as shown in Figures 6-8a-c, many of the values were close to or below the reported detection limit of the 6600 EDS sensor (±2 NTU). Note that, as calculated in this report, a difference between a reference value of 2 NTU and a 6600 EDS value of 1 NTU would be 100% even though both values are below the limit of detection.

The bias for chlorophyll ranged between 43% and 229%. As was the case with turbidity, these values are probably not reflective of the overall sensor performance because of at least two factors:

1. Many of the comparative values were taken at points where the chlorophyll readings were very low and thus below the detection limit of the 6600 EDS. As for turbidity, a difference between a reference value of 1 µg/L and a 6600 EDS value of 2 µg/L results in a bias of 100% even though both values are probably below the detection limits of the sensors.

2. The major contributor to high bias in the chlorophyll readings appears to be a single comparison during a "spike" of phytoplankton during the mesocosm study on September 21. Because the spike is so sharp, it is possible that a sampling error for the reference probe could be responsible for a significant portion of the apparent bias.

The 6600 EDS chlorophyll system is designed to track changes in phytoplankton in a water column on a semi-quantitative basis only. Therefore, as for turbidity above, a better representation of the sensor performance can probably be obtained by referring to the overall comparison of reference and logged readings.

### 6.3 Precision

Percent RSD was calculated during periods of stable operation in the mesocosm tank. Periods of stable operation typically corresponded to periods during the mesocosm test when the pump was not operating, periods during which the freshwater replaced the saltwater, or other periods during which the parameter in question showed no visible change in 6600 EDS measurements. Table 6-3 shows the results of these calculations and the period over which the calculations were made. No %RSD value was determined for turbidity because data from a period of stable operation were not available for analysis.

**Table 6-3. Percent Relative Standard Deviation for YSI AA and YSI AB During Periods of Stable Operation**

| Parameter | Stable Time Period Start | Stable Time Period Stop | Number of Measurements | %RSD YSI AA | %RSD YSI AB |
|---|---|---|---|---|---|
| DO | 9/24/02 6:00 AM | 9/24/02 10:00 AM | 17 | 12.5 | 12.6 |
| Conductivity | 9/24/02 4:30 PM | 9/24/02 11:00 PM | 27 | 1.06 | 1.07 |
| Temperature | 9/24/02 1:30 PM | 9/24/02 3:45 PM | 10 | 0.08 | 0.07 |
| pH | 9/24/02 7:00 AM | 9/24/02 9:30 AM | 11 | 0.00 | 0.00 |
| Turbidity | NA | NA | NA | NA | NA |
| Chlorophyll | 9/24/02 12:15 PM | 9/25/02 1:30 PM | 102 | 41.6 | 38.5 |

The pH and temperature had the lowest %RSD, ranging between 0.00%RSD and 0.08%RSD, and conductivity was 1.06%RSD and 1.07%RSD for the two probes. DO was 12.5%RSD and 12.6%RSD, and chlorophyll was 41.6%RSD and 38.5%RSD.

## 6.4 Linearity

Linearity was assessed by comparing probe readings against the reference values for each of the parameters at each deployment location. Table 6-4 gives the results of this comparison by showing the slope, intercept, and coefficient of determination ($r^2$) at each condition. Linear response was highest for conductivity and temperature, with slopes near 1 and $r^2$ values above 0.85. During the mesocosm deployment $r^2$ values above 0.80.

**Table 6-4. Results of Linearity Analysis for YSI AA and YSI AB**

| | | Saltwater | | | Freshwater | | | Mesocosm | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Unit** | **Parameter** | **Slope** | **Intercept** | **Coefficient of Determination** | **Slope** | **Intercept** | **Coefficient of Determination** | **Slope** | **Intercept** | **Coefficient of Determination** |
| AA | DO | 0.48 | 3.15 | 0.38 | 1.16 | 0.37 | 0.96 | 1.01 | 0.40 | 0.82 |
| AB | DO | 0.42 | 2.45 | 0.16 | 1.13 | 0.46 | 0.97 | 1.01 | 0.45 | 0.81 |
| AA | Conductivity | NA | NA | NA | 1.30 | -0.09 | 0.95 | 1.05 | -0.07 | 0.99 |
| AB | Conductivity | 1.12 | -0.14 | 0.97 | 1.3 | -0.0817 | 0.85 | 1.05 | -0.09 | 0.99 |
| AA | Temperature | 1.00 | -2.54 | 0.94 | 0.99 | 0.698 | 0.99 | 0.95 | 13.78 | 0.99 |
| AB | Temperature | 0.97 | 9.00 | 0.94 | 1.03 | -8.78 | 0.99 | 0.95 | 15.17 | 0.99 |
| AA | pH | 0.87 | 0.00 | 0.58 | 0.56 | 0.00 | 0.83 | 0.78 | 0.00 | 0.91 |
| AB | pH | 0.87 | 0.00 | 0.58 | 0.49 | 0.00 | 0.93 | 0.76 | 0.00 | 0.92 |
| AA | Turbidity | 0.55 | 1.56 | 0.44 | 0.65 | 0.54 | 0.39 | 1.44 | -3.14 | 0.99 |
| AB | Turbidity | 0.31 | 2.73 | 0.01 | 0.52 | -0.42 | 0.78 | 0.97 | -4.17 | 0.98 |
| AA | Chlorophyll | 1.38 | 0.65 | 0.76 | 1.21 | 42 | 0.01 | 3.22 | -4.42 | 0.99 |
| AB | Chlorophyll | 1.52 | 0.15 | 0.82 | 1.21 | 42 | 0.01 | 2.91 | -4.30 | 0.98 |

NA = No calculations performed.

## 6.5 Inter-Unit Reproducibility

Inter-unit reproducibility was assessed both by comparing the relative bias of the two 6600 EDSs (Section 6.2), as well as by comparing the average differences between the two 6600 EDS readings for each parameter at each deployment location. Figures 6-4 through 6-9 show the data used for these calculations. These calculations were made for the readings where there was an analogous reference measurement only. The results of average difference comparisons are shown in Table 6-5.

**Table 6-5. Average Difference in YSI AA and YSI AB Readings for Each Parameter at Each Deployment Location**

| | Average Difference Between YSI AA and YSI AB | | | | | |
|---|---|---|---|---|---|---|
| **Location** | **DO (mg/L)** | **Conductivity (mS/cm)** | **Temperature (C)** | **pH** | **Turbidity (NTU)** | **Chlorophyll (total)** |
| Saltwater | 0.21 | 0.07 | 0.07 | 0.02 | 1.92 | 1.01 |
| Freshwater | 0.45 | 0.01 | 0.11 | 0.07 | 8.33 | NA |
| Mesocosm | 0.08 | 0.22 | 0.10 | 0.02 | 3.78 | 0.84 |
| Average | 0.25 | 0.10 | 0.09 | 0.03 | 4.68 | 0.92 |

The DO difference between the two 6600 EDSs tested averaged 0.25 mg/L, while the actual DO readings varied from 0 to 18 mg/L (Figures 6-4a-c). The difference in conductivity averaged 0.10 mS/cm over a range of 0.3 to 49 mS/cm (Figures 6-5a-c). The average difference in temperature readings was 0.09°C, with actual temperature readings ranging between 24 and 35°C (Figures 6-6a-c). The average difference in pH readings was 0.03 over a range of 6.8 to 8.7 (Figures 6-7a-c). The average difference in turbidity readings was 4.68 NTU, while actual turbidity readings ranged from 0 to 197 NTU (Figures 6-8a-c). Finally, chlorophyll readings had an average difference of 0.92, while actual chlorophyll readings varied from 0 to 154 (Figures 6-9a-c).

The magnitude of the inter-unit reproducibility results was affected by spatial and temporal changes in the sampling environment. For example, the 6600 EDSs were sampling in an environment that was changing 8°C over a 24-hour period. Because they were not sampling in exactly the same location, differences in temperature, caused by the 24-hour fluctuations, resulted in some differences in measurement by the 6600 EDSs. Similar behavior occurs in any location that experiences similar dynamic changes in the environment.

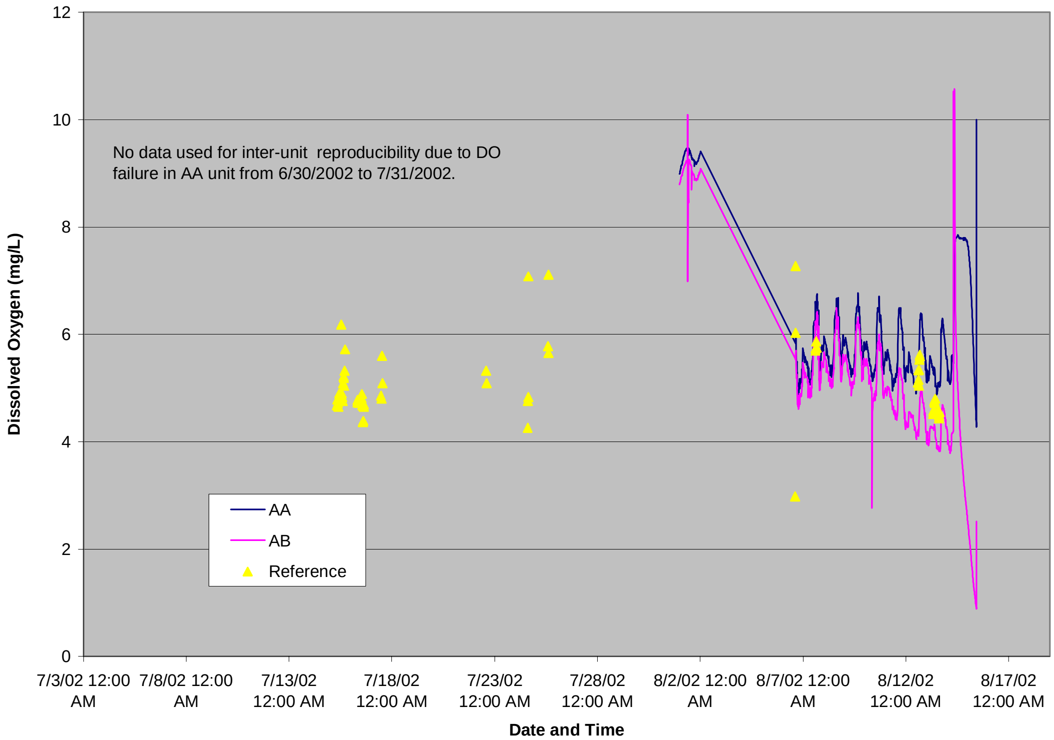



**Figure 6-4a. Inter-Unit Reproducibility Data for Dissolved Oxygen During Saltwater Tests**

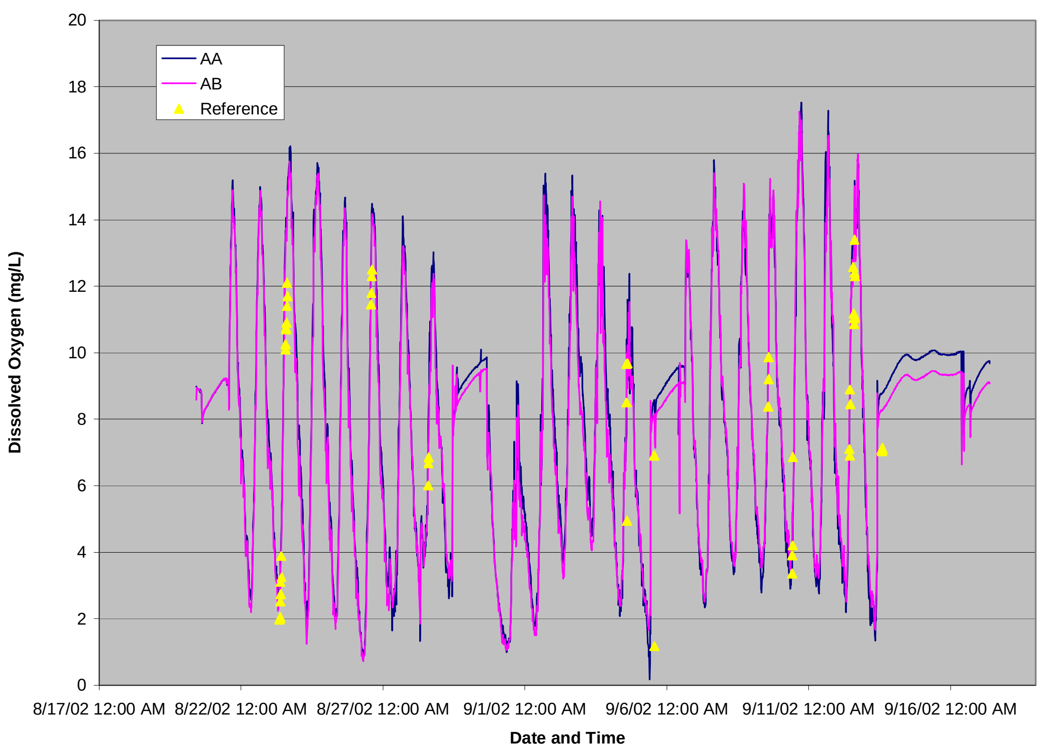



**Figure 6-4b. Inter-Unit Reproducibility Data for Dissolved Oxygen During Freshwater Tests**

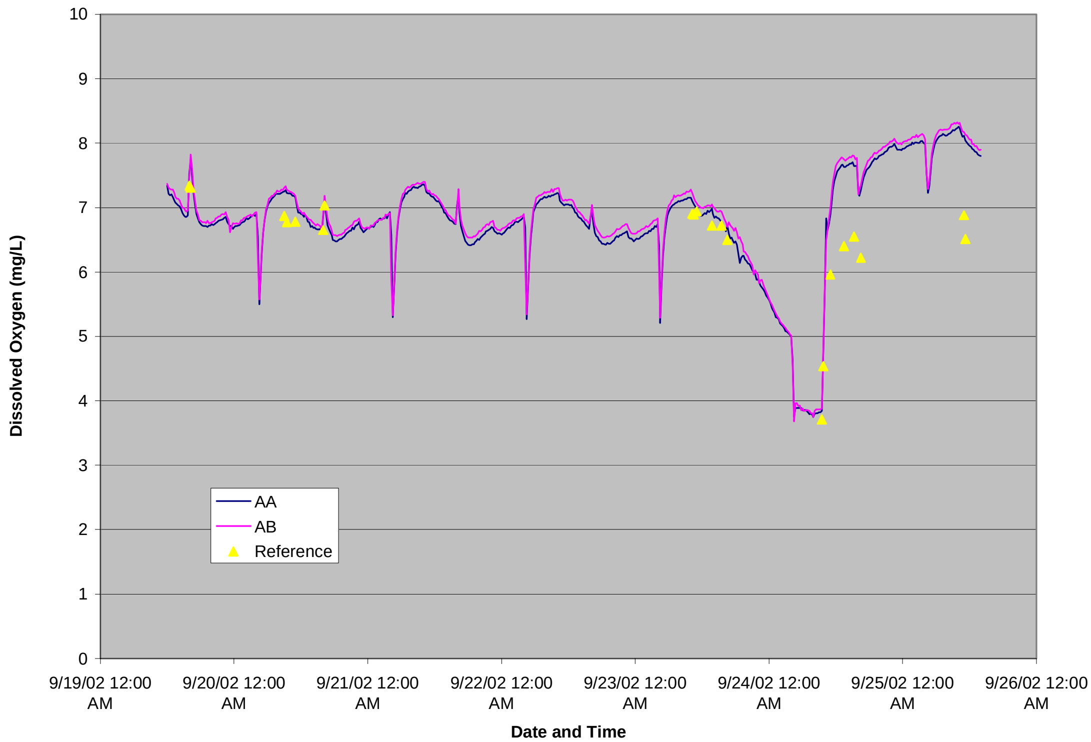



**Figure 6-4c. Inter-Unit Reproducibility Data for Dissolved Oxygen During Mesocosm Tests**

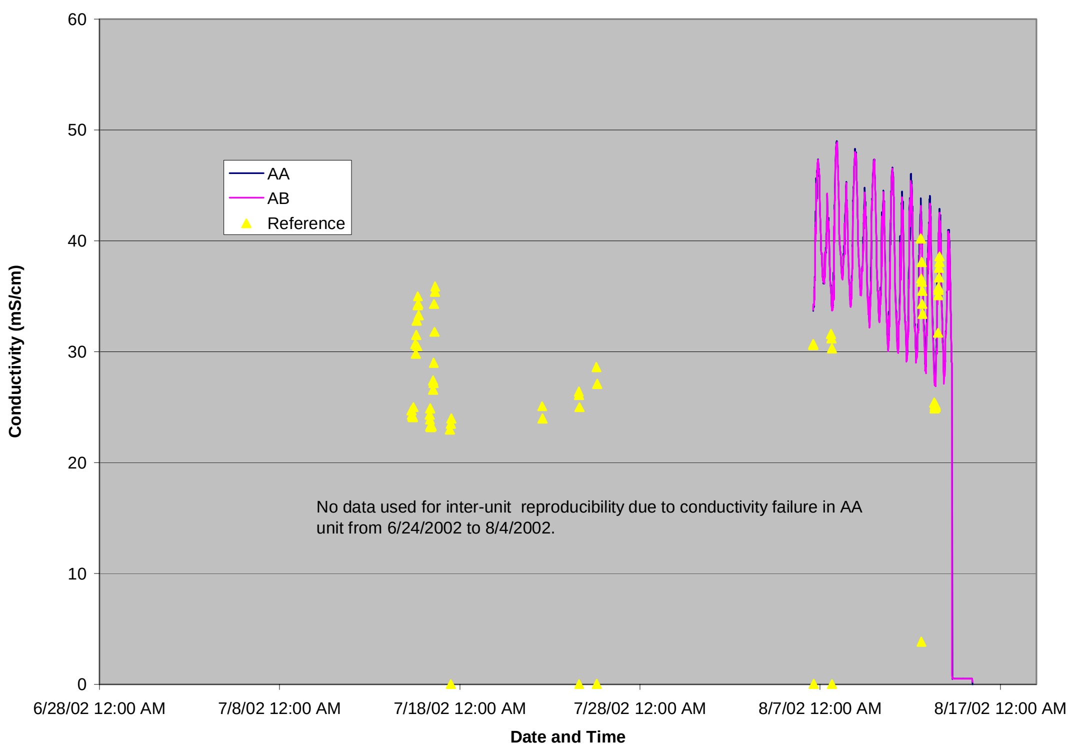



**Figure 6-5a. Inter-Unit Reproducibility Data for Conductivity During Saltwater Tests**

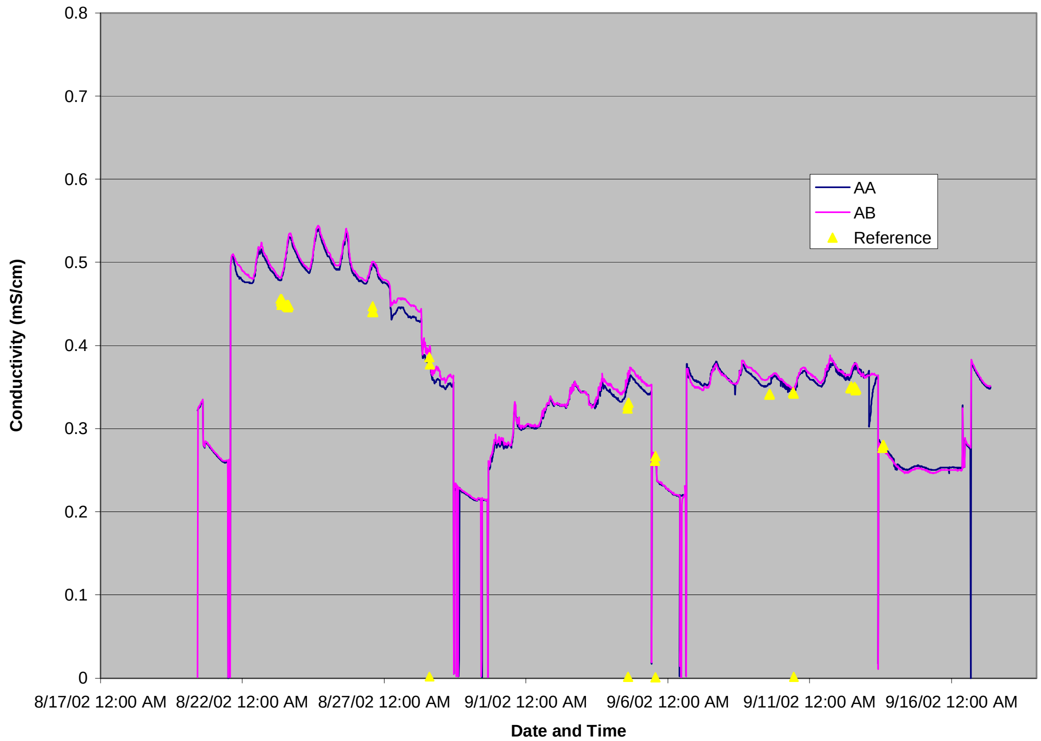



**Figure 6-5b. Inter-Unit Reproducibility Data for Conductivity During Freshwater Tests**

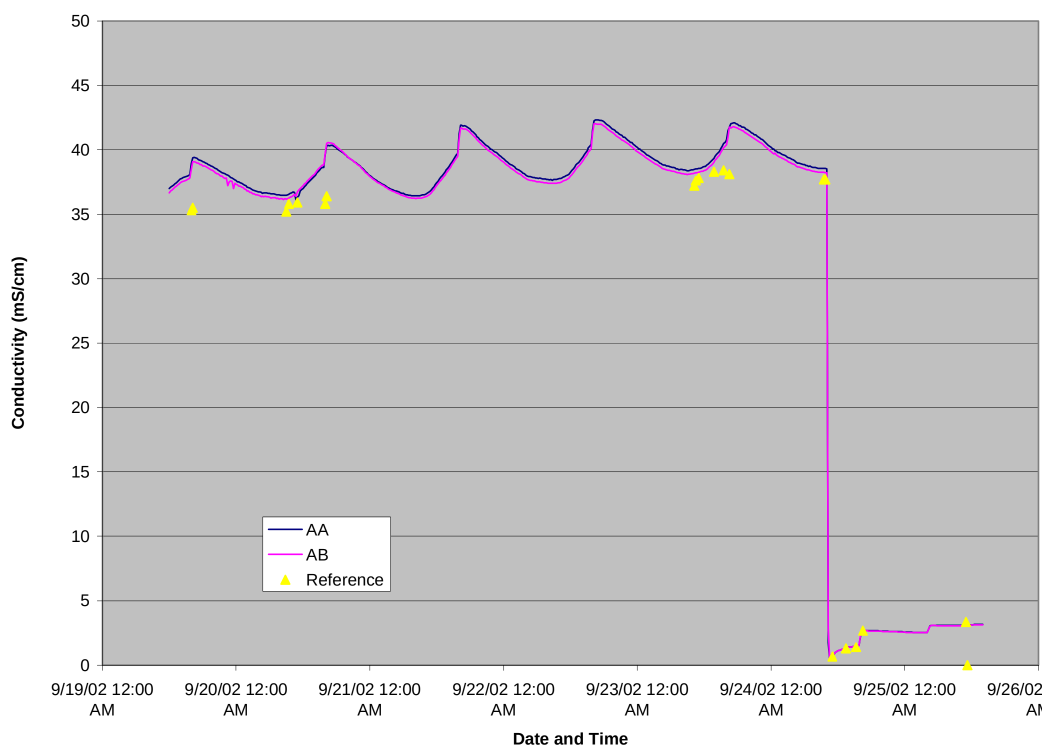



**Figure 6-5c. Inter-Unit Reproducibility Data for Conductivity During Mesocosm Tests**

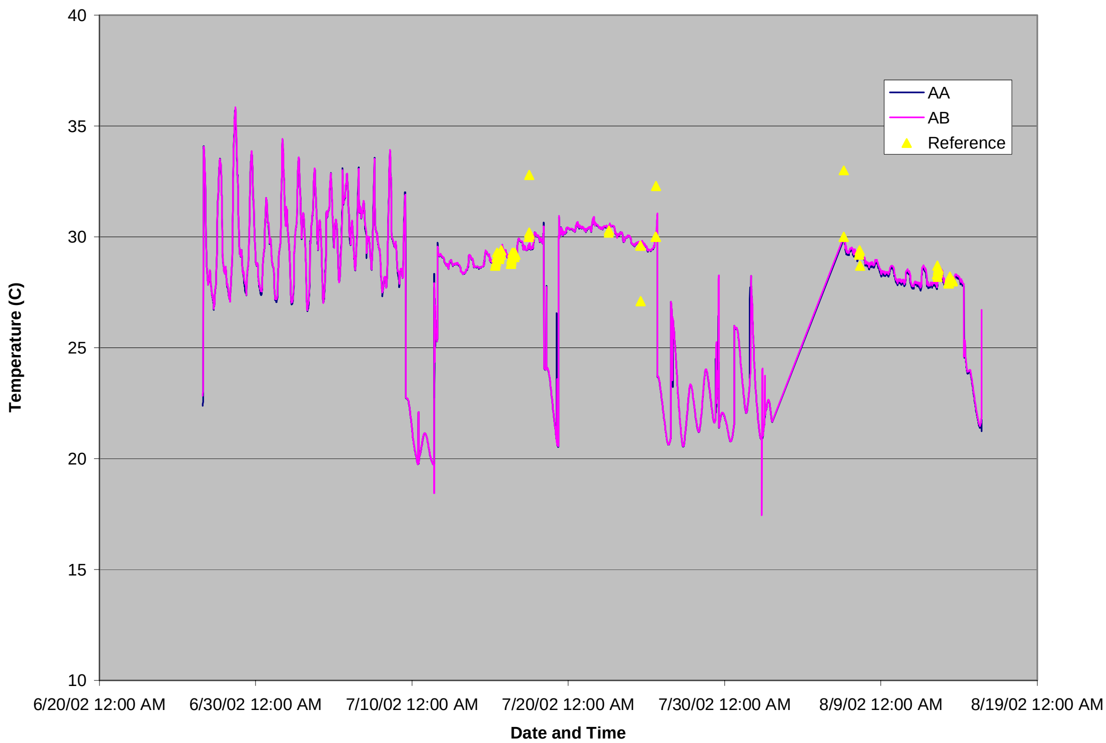



**Figure 6-6a. Inter-Unit Reproducibility Data for Temperature During Saltwater Tests**

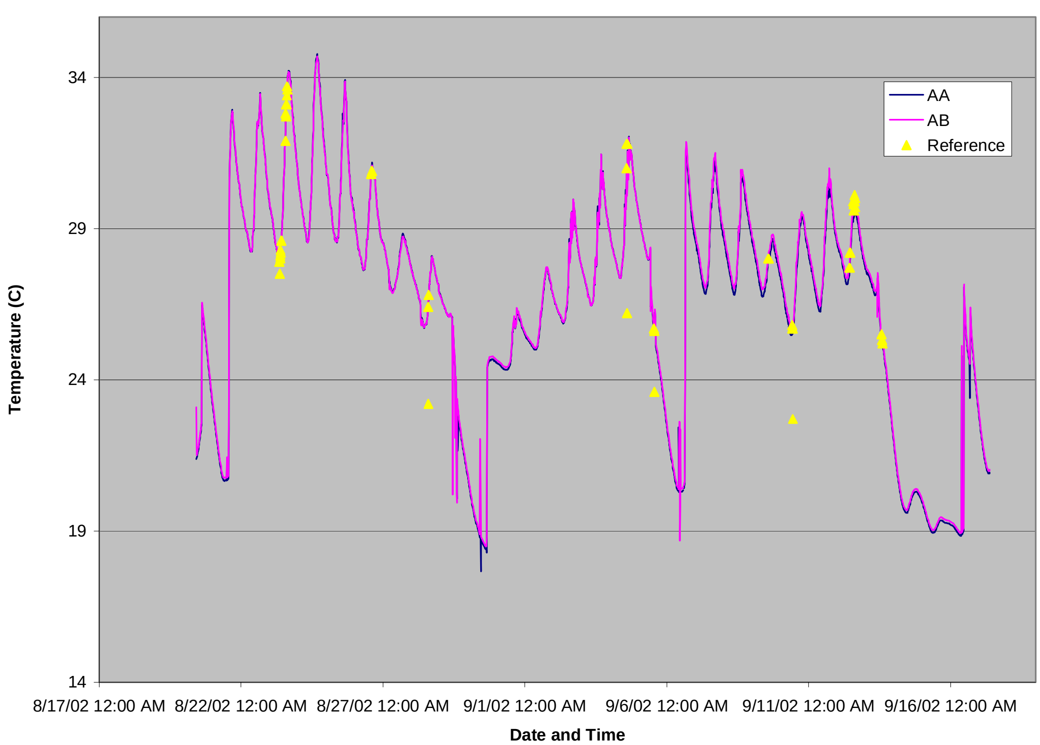



**Figure 6-6b. Inter-Unit Reproducibility Data for Temperature During Freshwater Tests**

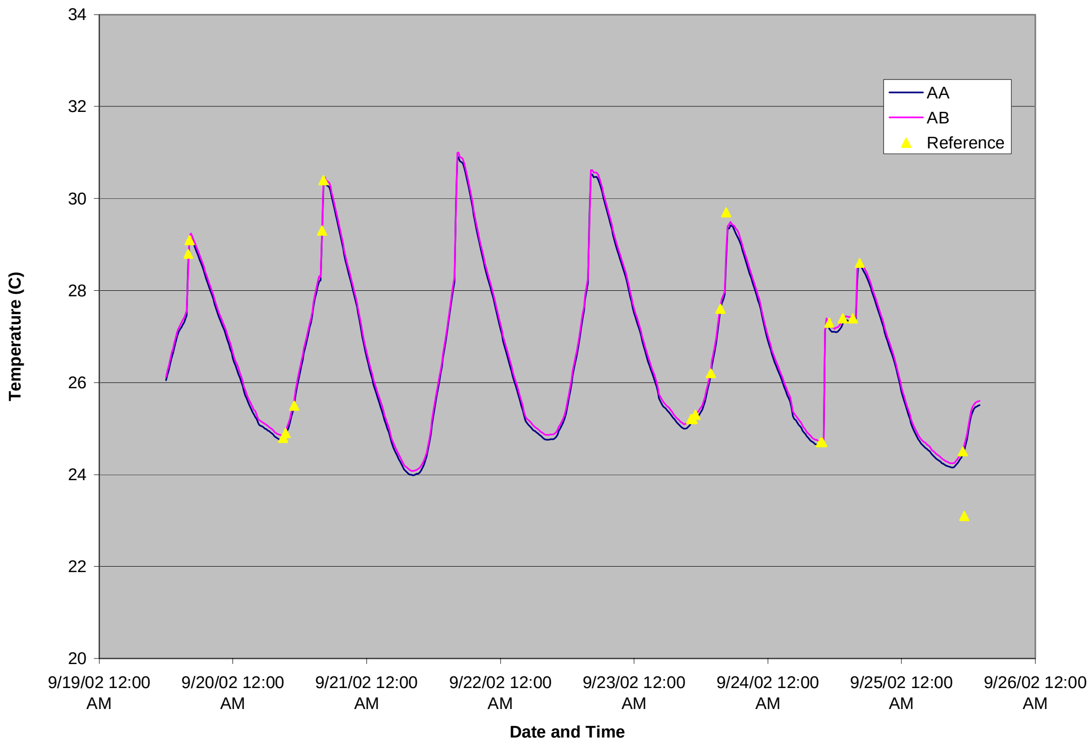



**Figure 6-6c. Inter-Unit Reproducibility Data for Temperature During Mesocosm Tests**

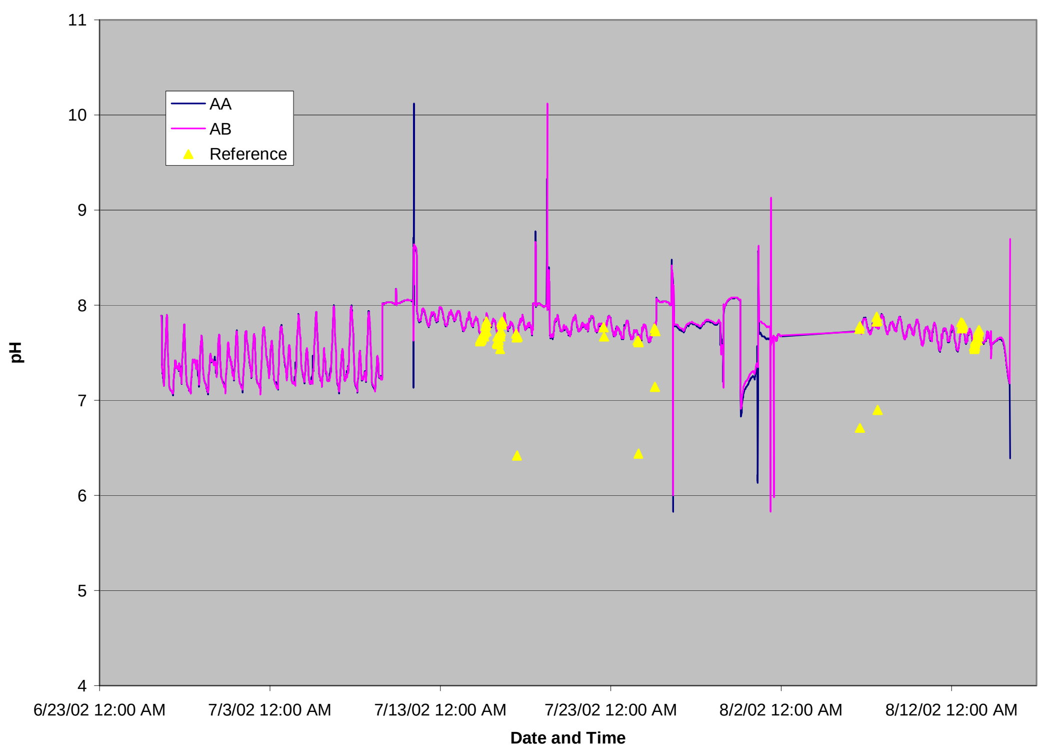



**Figure 6-7a. Inter-Unit Reproducibility Data for pH During Saltwater Tests**

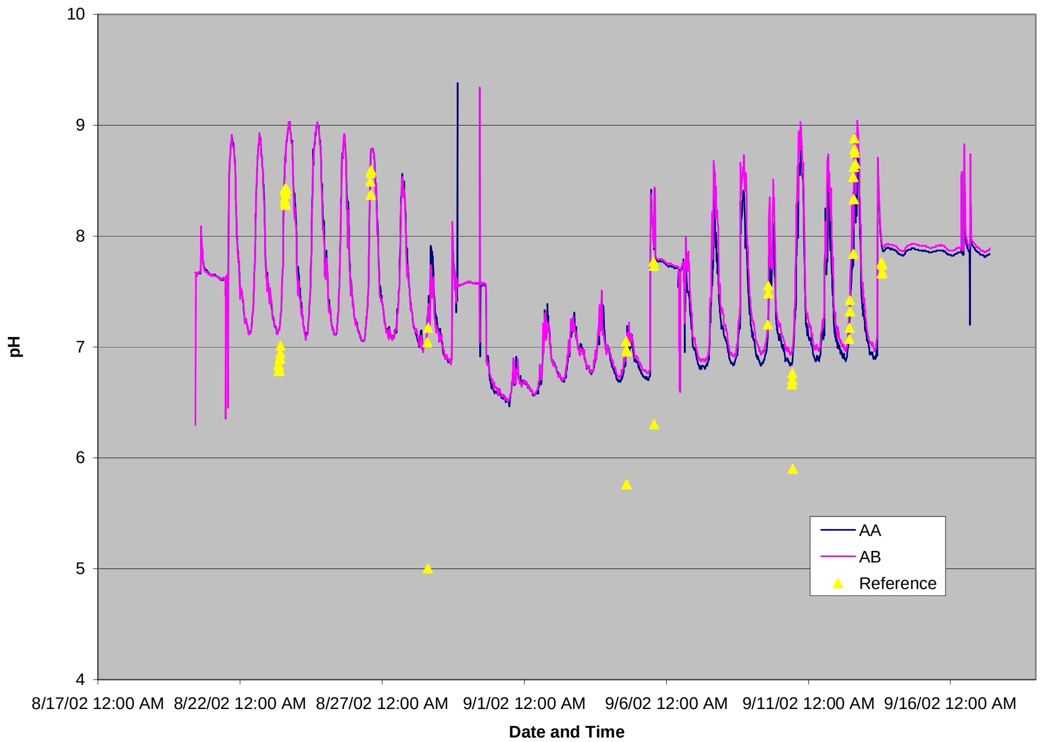



**Figure 6-7b. Inter-Unit Reproducibility Data for pH During Freshwater Tests**

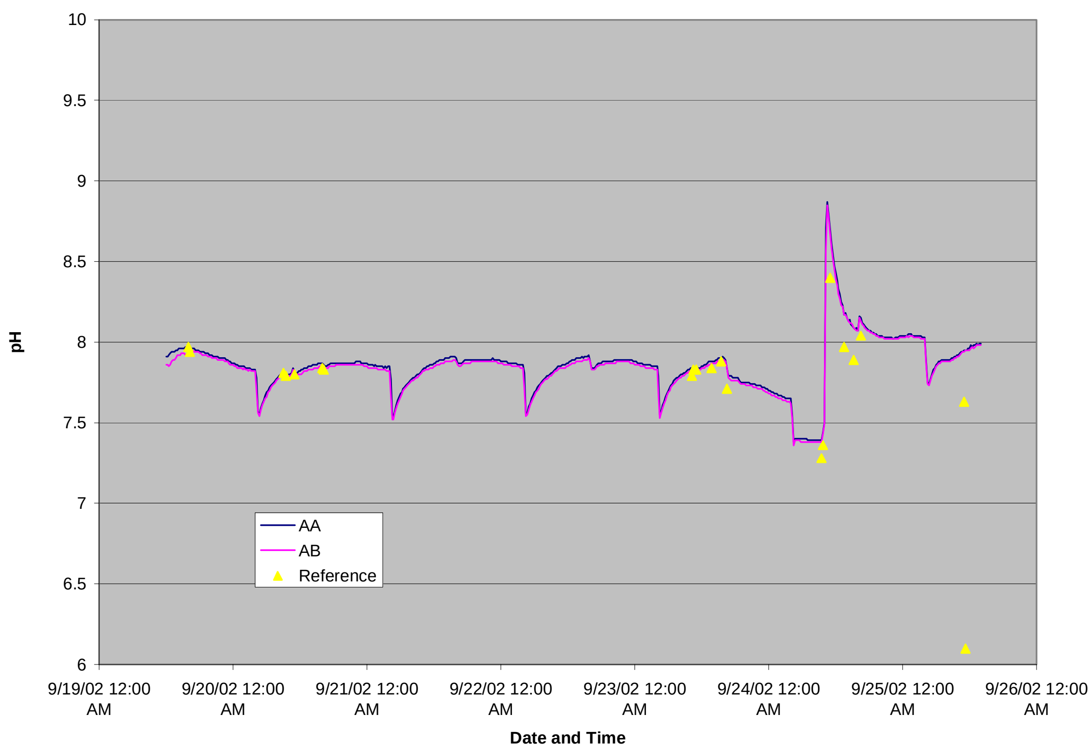



**Figure 6-7c. Inter-Unit Reproducibility Data for pH During Mesocosm Tests**

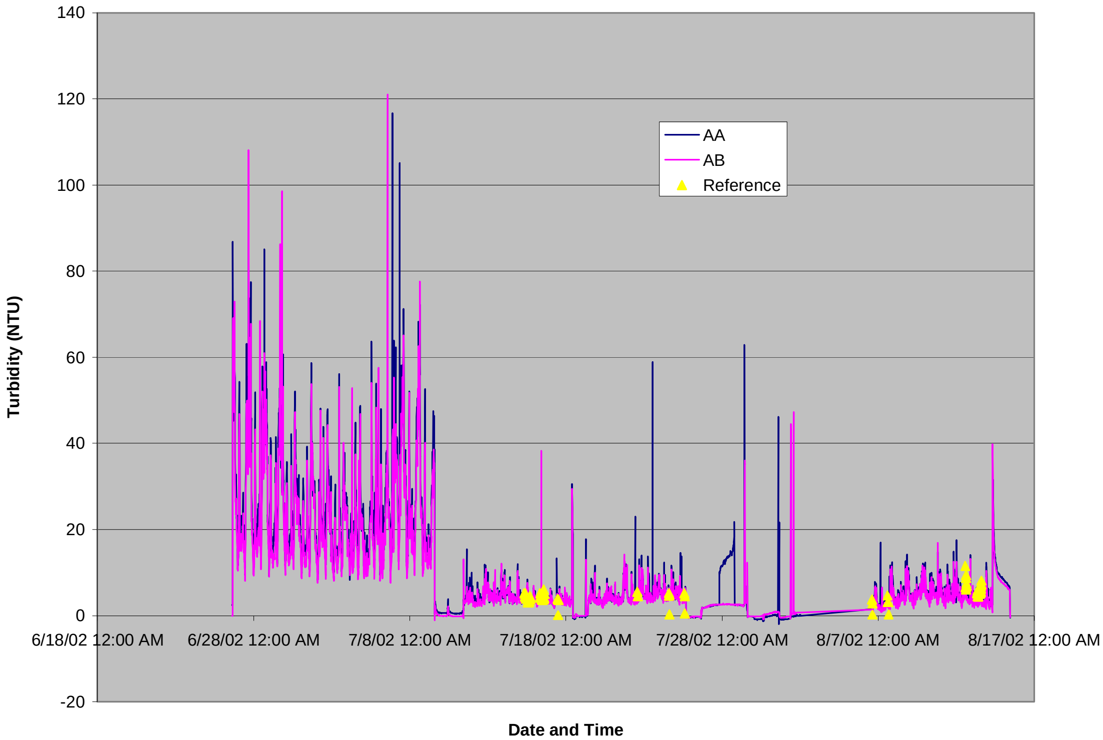



**Figure 6-8a. Inter-Unit Reproducibility Data for Turbidity During Saltwater Tests**

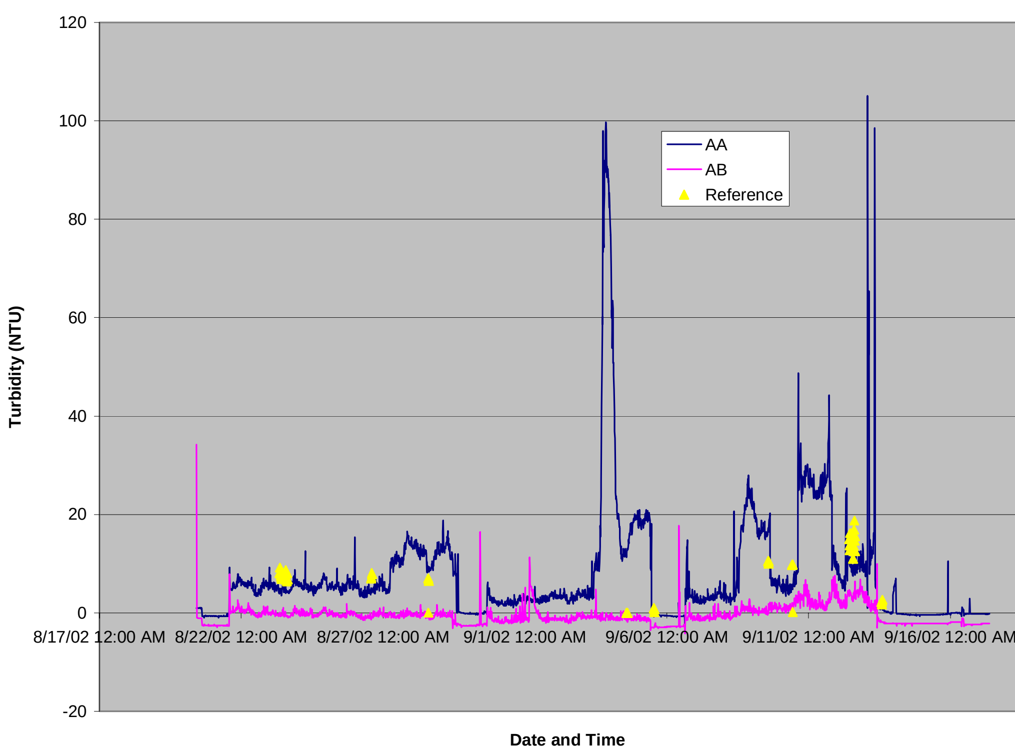



**Figure 6-8b. Inter-Unit Reproducibility Data for Turbidity During Freshwater Tests**

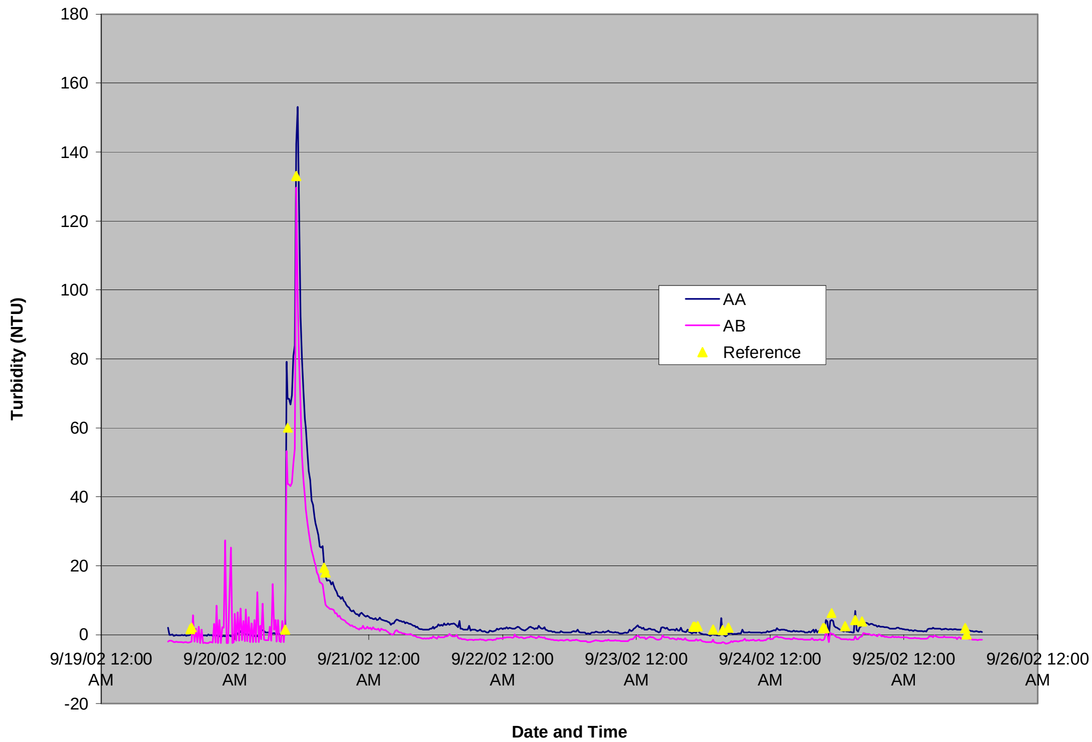



**Figure 6-8c. Inter-Unit Reproducibility Data for Turbidity During Mesocosm Tests**

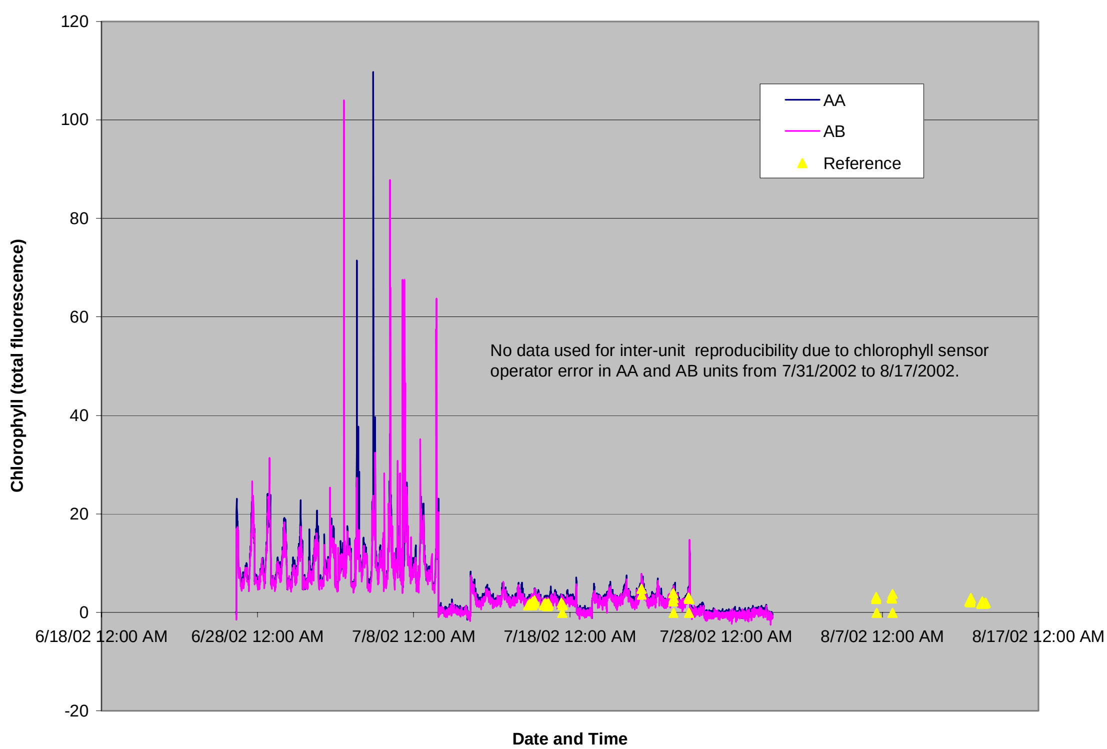



**Figure 6-9a. Inter-Unit Reproducibility Data for Chlorophyll During Saltwater Tests**

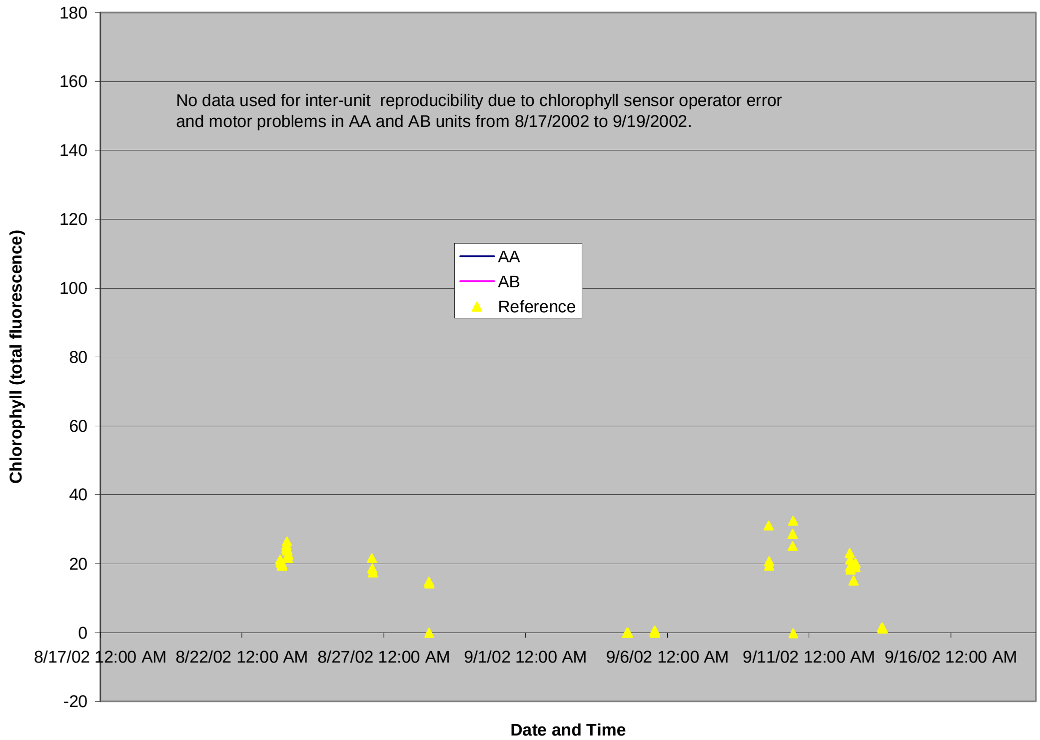



**Figure 6-9b. Inter-Unit Reproducibility Data for Chlorophyll During Freshwater Tests**

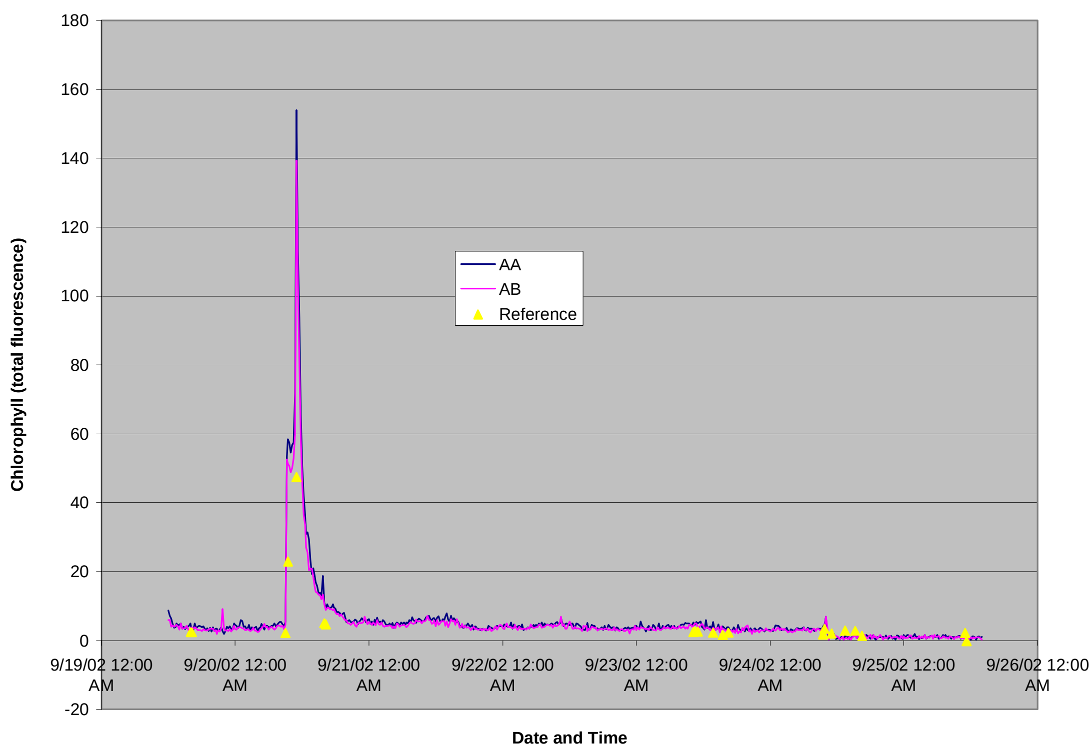



**Figure 6-9c. Inter-Unit Reproducibility Data for Chlorophyll During Mesocosm Tests**

## 6.6 Other Factors

### *6.6.1 Ease of Use*

The 6600 EDSs were set up to collect data with minimal difficulty, and data were downloaded without incident using the provided data cable and a PC. The 6600 EDS operators during this verification test included individuals with and without a college education, all of whom had some experience working with monitoring equipment. The 6600 EDSs were transported to and from the testing sites in a five-gallon bucket wrapped in wet towels. Both the calibrations for each of the parameters and the replacement DO membranes proceeded without difficulty according to the manufacturer's instructions.

### *6.6.2 Costs*

At the time of testing, the 6600 EDS, as verified, cost $10,740 per unit.

### *6.6.3 Data Completeness*

All portions of the verification test were completed; however, because of a problem with a non-functioning membrane, several days of data collection were excluded as a result of known problems. The YSI DO membranes were replaced on both probes on July 26, 2002, at the manufacturer recommended frequency (one month). It was determined that the membranes probably had been damaged before this date, either as a result of operator error or during the redeployment from the first to the second saltwater site. The DO membranes were changed again on August 19.

The conductivity/temperature sensor of YSI AA was replaced on August 5, 2002. On August 16, it was determined that the chlorophyll sensor had not been working properly for approximately two weeks. This was because the wiper head was installed incorrectly. The wipers on both 6600 EDSs for both the turbidity and chlorophyll sensors were changed on August 16.

On August 29, both the turbidity and the chlorophyll wipers were parking correctly; however, when calibration was checked on September 17, the YSI AB wipers were parked on the turbidity and chlorophyll optics, resulting in irregular data for both turbidity and chlorophyll. The problem continued after testing staff attempted to fix the problem. The YSI AB chlorophyll sensor was replaced, but the wiper parking problem continued throughout the remainder of the freshwater deployment. YSI traced the problem to the wiper motor. The new motor design was installed for the mesocosm test, and no wiper parking problems were noted. In addition, there were no further wiper problems during a two-month deployment of YSI AA and YSI AB by NOAA CCEHBR immediately following this verification test.

Because several of the sensors did not function properly during the verification test, approximately 28% of the measurements were excluded.

# Chapter 7
# Performance Summary

Pre-and post-calibration tests showed that pH measurement were accurate within a range of 99 to 102% of the true values. Except for the very first result of 73%, the remaining DO measurement values were accurate within a range of 100 to 109% of the true values. Conductivity measurement values were accurate within a range of 98 to 104% of the true values.

The relative bias for the temperature, conductivity, pH, and DO parameters was less than -28% in saltwater, freshwater, and the mesocosm. The bias for temperature was less than 0.1% and for conductivity less than 12%. The DO bias was less than 13.23% at the saltwater site and in the mesocosm, but averaged 22% at the freshwater site. Variability in DO concentration was much greater at the freshwater site, and DO measurements were consistently higher than reported by the reference unit. The higher DO bias could be, at least partially, because the reference unit (unlike the 6600 EDS) required a large flow dependence, making it necessary to move the sensor rapidly up and down in the water column. Inadequate agitation resulting in erroneously low DO values could explain some of the bias in the relative DO readings. The bias for pH was calculated at an average of -28%, when using units of mol/L of $H^+$ concentration, which is within the accuracy specification of the system. The bias for turbidity ranged between -9.54% and -126%, but many of the values were close to or below the reported detection limit of the 6600 EDS. The bias for chlorophyl ranged between 43.0% and 229%; however, many of the values were taken at points where chlorophyll readings were very low; and, in addition, there was a sharp spike of phytoplankton during the mesocosm study.

Percent RSD was lowest for the pH and temperature, ranging between 0.00%RSD and 0.08%RSD. Precision for conductivity was 1.06%RSD and 1.07%RSD for the two 6600 EDSs. For DO it was 12.5%RSD and 12.6%RSD, and for chlorophyll 41.6%RSD and 38.5%RSD.

The linear response for the 6600 EDS, expressed in terms of slope, intercept, and coefficient of determination at each condition, was highest for conductivity and temperature, with a strong correlation for all the parameters during mesocosm deployment.

Analysis of inter-unit reproducibility showed that the average difference in DO measurements between the two 6600 EDSs tested was 0.25 mg/L, while the readings for DO concentration varied from 3 to 15 mg/L. The difference in conductivity averaged 0.10 mS/cm over a range of 0.3 to 44 mS/cm. The average difference in temperature readings was 0.09°C, with actual temperature readings ranging between 24 and 35°C. The average difference in pH readings was 0.03 over a range of 6.8 to 8.7. The average difference in turbidity reading was 4.68 NTU, while actual turbidity readings ranged from 0 to 197 NTU. Finally, chlorophyll readings had an average difference of 0.92, while actual chlorophyll readings varied from 0 to 154.

The magnitude of the inter-unit reproducibility results was affected by spatial and temporal changes in the sampling environment. For example, the 6600 EDSs were sampling in an environment that was changing 8°C over a 24-hour period. Because they were not sampling in exactly the same location, differences in temperature, caused by the 24-hour fluctuations, resulted in some differences in measurement by the 6600 EDSs. Similar behavior occurs in any location that experiences similar dynamic changes in the environment.

The 6600 EDSs were set up to collect data with minimal difficulty, and data were downloaded without incident using the provided data cable and a PC. All portions of the verification test were completed. However, there were periods of operation where known issues (such as erroneous readings from improperly installed sensors and a puncture in a sensor possibly by a small marine animal) probably affected the performance of one of the 6600 EDSs. Approximately 28% of the data were affected in this manner and excluded from the data analysis.

The 6600 EDS, as verified in this test, cost $10,740 per unit.

# Chapter 8
# References


1. *Test/QA Plan for Long-Term Deployment of Multi-Parameter Water Quality Probes/Sondes*, Battelle, Columbus, Ohio, Version 2.0, May 2002.

2. *Quality Management Plan (QMP) for the ETV Advanced Monitoring Systems Center*, Version 3.0, U.S. EPA Environmental Technology Verification Program, Battelle, Columbus, Ohio, December 2001.

# Appendix A
# Reference Sample and Probe Readings

| | YSI AA | | | | | | YSI AB | | | | | | Reference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m/d/y hh:mm | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total |
| 7/15/02 8:00 AM | 28.61 | 24.06 | 4.88 | 7.70 | 5 | 2.8 | 28.65 | 27.71 | 4.86 | 7.70 | 4.7 | 2.6 | 28.55 | 24.7 | 4.68 | 7.62 | 5.2 | 1.45 |
| 7/15/02 8:30 AM | 28.62 | 23.34 | 4.91 | 7.68 | 4.1 | 2.5 | 28.66 | 26.83 | 4.86 | 7.68 | 4.9 | 1.9 | 28.65 | 24.3 | 4.79 | 7.64 | 5.2 | 1.43 |
| 7/15/02 9:00 AM | 28.62 | 23.51 | 4.86 | 7.68 | 4.5 | 2.9 | 28.65 | 27.06 | 4.77 | 7.68 | 4.3 | 1.8 | 28.75 | 24.2 | 4.72 | 7.63 | 4.4 | 1.48 |
| 7/15/02 9:30 AM | 28.67 | 23.12 | 4.96 | 7.69 | 3 | 3.6 | 28.7 | 26.59 | 4.81 | 7.69 | 3.3 | 2.9 | 28.75 | 24.1 | 4.65 | 7.64 | 5.2 | 1.55 |
| 7/15/02 10:00 AM | 28.69 | 23.20 | 4.9 | 7.69 | 5.3 | 2.9 | 28.73 | 26.79 | 4.78 | 7.69 | 5.1 | 2.7 | 28.95 | 24.1 | 4.81 | 7.67 | 4.7 | 1.75 |
| 7/15/02 10:30 AM | 28.69 | 24.05 | 4.77 | 7.69 | 4.9 | 2.9 | 28.77 | 27.58 | 4.58 | 7.69 | 4 | 1.3 | 29.15 | 25 | 4.9 | 7.65 | 4 | 1.45 |
| 7/15/02 1:00 PM | 28.68 | 29.36 | 4.42 | 7.78 | 4.1 | 3.1 | 28.72 | 34.18 | 4.26 | 7.78 | 3.5 | 2.9 | 29.05 | 30.7 | 6.18 | 7.69 | 4 | 1.89 |
| 7/15/02 1:30 PM | 28.7 | 30.83 | 4.37 | 7.81 | 3.9 | 3.4 | 28.73 | 36.85 | 4.22 | 7.81 | 4.1 | 2.6 | 28.95 | 29.8 | 4.9 | 7.71 | 3 | 1.49 |
| 7/15/02 2:00 PM | 28.69 | 33.57 | 4.28 | 7.85 | 5.9 | 3.2 | 28.73 | 39.49 | 4.13 | 7.85 | 5 | 2.8 | 28.85 | 31.5 | 4.83 | 7.67 | 3.5 | 1.94 |
| 7/15/02 2:30 PM | 28.69 | 33.56 | 4.28 | 7.85 | 4.4 | 3.1 | 28.73 | 39.63 | 4.17 | 7.85 | 4.2 | 2 | 28.95 | 32.8 | 4.76 | 7.71 | 3.3 | 1.87 |
| 7/15/02 3:00 PM | 28.73 | 32.40 | 4.32 | 7.83 | 3.6 | 3.2 | 28.77 | 37.92 | 4.22 | 7.83 | 3.7 | 2.6 | 29.05 | 32.8 | 5.09 | 7.73 | 3.4 | 2.15 |
| 7/15/02 3:30 PM | 28.85 | 30.59 | 4.45 | 7.82 | 2.9 | 3.4 | 28.92 | 35.65 | 4.34 | 7.82 | 2.9 | 3.6 | 29.15 | 30.5 | 5.22 | 7.78 | 3.1 | 2.18 |
| 7/15/02 4:00 PM | 28.91 | 31.77 | 4.44 | 7.84 | 3 | 3.5 | 28.9 | 38.06 | 4.31 | 7.84 | 3.2 | 2.7 | 29.15 | 34.2 | 5.19 | 7.78 | 3.4 | 1.84 |
| 7/15/02 4:30 PM | 28.86 | 33.06 | 4.31 | 7.85 | 3.7 | 3.1 | 28.92 | 38.70 | 4.3 | 7.85 | 3.6 | 1.5 | 29.05 | 35 | 5.04 | 7.80 | 4.5 | 1.79 |
| 7/15/02 5:00 PM | 28.98 | 32.44 | 4.47 | 7.85 | 3.2 | 3.8 | 29.02 | 38.19 | 4.46 | 7.85 | 3.3 | 2.7 | 29.25 | 34.3 | 5.32 | 7.73 | 4.4 | 2.02 |
| 7/15/02 5:15 PM | 29.27 | 31.33 | 5.02 | 7.92 | 3.4 | 4.3 | 29.33 | 36.47 | 5.06 | 7.92 | 3.4 | 4 | 29.25 | 33.3 | 5.72 | 7.83 | 3.8 | 2.41 |
| 7/16/02 8:00 AM | 28.74 | 23.69 | 4.67 | 7.71 | 3.7 | 1.8 | 28.78 | 27.31 | 4.74 | 7.71 | 3.6 | 1.6 | 28.65 | 24.3 | 4.73 | 7.61 | 4.2 | 1.48 |
| 7/16/02 8:15 AM | 28.75 | 23.62 | 4.69 | 7.72 | 4.4 | 2.4 | 28.8 | 27.30 | 4.8 | 7.72 | 5 | 2.5 | 28.65 | 23.9 | 4.78 | 7.60 | 4.1 | 1.54 |
| 7/16/02 8:30 AM | 28.75 | 23.89 | 4.7 | 7.71 | 4.5 | 2.4 | 28.79 | 27.46 | 4.74 | 7.71 | 4 | 1.8 | 28.75 | 24.9 | 4.76 | 7.67 | 5.2 | 1.66 |
| 7/16/02 9:00 AM | 28.77 | 22.64 | 4.68 | 7.68 | 4.4 | 2.5 | 28.81 | 26.02 | 4.83 | 7.68 | 4 | 2.3 | 28.85 | 23.3 | 4.75 | 7.61 | 4.4 | 1.61 |
| 7/16/02 9:30 AM | 28.82 | 22.29 | 4.73 | 7.67 | 4.2 | 2.8 | 28.85 | 25.64 | 4.76 | 7.67 | 3.5 | 2.3 | 28.95 | 23.2 | 4.72 | 7.59 | 4.5 | 1.74 |
| 7/16/02 10:00 AM | 28.82 | 22.51 | 4.74 | 7.67 | 3.7 | 2.1 | 28.86 | 25.93 | 4.69 | 7.67 | 3 | 2.3 | 28.95 | 23.4 | 4.8 | 7.64 | 4.4 | 1.85 |
| 7/16/02 10:15 AM | 28.87 | 22.38 | 4.76 | 7.67 | 3.7 | 2.7 | 28.91 | 25.70 | 4.73 | 7.67 | 38.3 | 2.7 | 29.05 | 23.4 | 4.8 | 7.63 | 4.4 | 1.76 |
| 7/16/02 10:30 AM | 28.92 | 22.25 | 4.77 | 7.67 | 3.6 | 3.3 | 28.96 | 25.60 | 4.74 | 7.67 | 2.9 | 2.1 | 29.15 | 23.3 | 4.76 | 7.60 | 3.7 | 1.55 |
| 7/16/02 12:30 PM | 28.84 | 24.45 | 4.51 | 7.69 | 5 | 2.3 | 28.87 | 28.40 | 4.43 | 7.69 | 4 | 1.2 | 29.05 | 26.6 | 4.81 | 7.54 | 3.6 | 1.31 |
| 7/16/02 12:45 PM | 28.81 | 25.26 | 4.32 | 7.69 | 5.1 | 2.8 | 28.85 | 28.70 | 4.33 | 7.69 | 4.3 | 2.8 | 29.05 | 27.4 | 4.81 | 7.67 | 5.1 | 1.65 |
| 7/16/02 1:00 PM | 28.81 | 25.33 | 4.33 | 7.70 | 4.2 | 3.4 | 28.86 | 29.00 | 4.33 | 7.70 | 4.9 | 2.2 | 29.15 | 27.2 | 4.89 | 7.70 | 5.5 | 1.62 |
| 7/16/02 1:30 PM | 28.83 | 28.60 | 4.17 | 7.76 | 4.7 | 3.4 | 28.87 | 33.17 | 4.19 | 7.76 | 4.2 | 2.1 | 28.95 | 29 | 4.68 | 7.73 | 3.8 | 1.29 |
| 7/16/02 2:00 PM | 28.89 | 31.80 | 4.15 | 7.82 | 4.5 | 2.4 | 28.93 | 37.14 | 4.12 | 7.82 | 4.2 | 3 | 29.05 | 34.3 | 4.37 | 7.82 | 6.1 | 1.68 |
| 7/16/02 2:30 PM | 28.91 | 31.46 | 4.15 | 7.82 | 3.8 | 2.9 | 28.96 | 36.14 | 4.2 | 7.82 | 3.2 | 2.3 | 29.05 | 31.8 | 4.39 | 7.81 | 4.1 | 1.65 |
| 7/16/02 3:00 PM | 28.9 | 33.85 | 4.06 | 7.85 | 4.4 | 2.4 | 28.94 | 39.83 | 4.06 | 7.85 | 4 | 2.6 | 29.05 | 35.4 | 4.7 | 7.80 | 3.9 | 1.45 |
| 7/16/02 3:15 PM | 28.91 | 33.71 | 4.06 | 7.85 | 4.3 | 2.8 | 28.94 | 40.03 | 4.03 | 7.85 | 4.3 | 2.3 | 29.05 | 35.9 | 4.65 | 7.83 | 5 | 1.82 |

| m/d/y hh:mm | YSI AA | | | | | | YSI AB | | | | | | Reference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total |
| 7/22/02 2:00 PM | 30.12 | 24.77 | 4.48 | 7.79 | 5.6 | 7.8 | 30.15 | 28.87 | 4.98 | 7.79 | 4.3 | 7.8 | 30.05 | 25.1 | 5.32 | 7.77 | 5.49 | 4.74 |
| 7/22/02 2:30 PM | 30.18 | 23.85 | 4.36 | 7.72 | 6.4 | 6 | 30.23 | 27.79 | 4.85 | 7.72 | 5.9 | 4.8 | 30.15 | 24 | 5.09 | 7.67 | 4.54 | 3.57 |
| 7/24/02 2:30 PM | 29.47 | 25.29 | 4 | 7.68 | 4.7 | 4.1 | 29.5 | 29.67 | 4.54 | 7.68 | 4.3 | 4.4 | 29.45 | 26.4 | 4.26 | 7.63 | 5.27 | 3.89 |
| 7/24/02 2:45 PM | 29.46 | 25.01 | 3.98 | 7.68 | 4.9 | 4.4 | 29.49 | 29.28 | 4.54 | 7.68 | 4.3 | 3.5 | 29.45 | 26.1 | 4.76 | 7.63 | 4.62 | 2.21 |
| 7/24/02 3:30 PM | 29.45 | 23.97 | 4.05 | 7.67 | 3.9 | 5.5 | 29.49 | 28.07 | 4.55 | 7.67 | 4 | 5.3 | 29.45 | 25 | 4.83 | 7.61 | 4.8 | 2.9 |
| 7/25/02 2:15 PM | 29.82 | 27.28 | 4.28 | 7.81 | 3.6 | 5.1 | 29.87 | 32.07 | 4.95 | 7.81 | 3.2 | 4.3 | 29.85 | 28.6 | 5.78 | 7.76 | 5.21 | 3.02 |
| 7/25/02 3:00 PM | 29.86 | 25.65 | 4.26 | 7.77 | 3.8 | 4.6 | 29.91 | 30.02 | 4.91 | 7.77 | 3 | 3.9 | 29.85 | 27.1 | 5.65 | 7.73 | 4.43 | 2.7 |
| 8/6/02 2:45 PM | 29.73 | 33.69 | 5.85 | 7.72 | 1.5 | 5 | 29.85 | 33.77 | 5.56 | 7.72 | 1.4 | 6.9 | 29.85 | 30.6 | 2.98 | 7.75 | 3.72 | 2.66 |
| 8/6/02 3:00 PM | 29.73 | 34.17 | 5.83 | 7.73 | 1.9 | 4.7 | 29.85 | 34.29 | 5.53 | 7.73 | 1.6 | 9 | 29.85 | 30.7 | 6.03 | 7.78 | 2.8 | 3.14 |
| 8/7/02 2:30 PM | 29.01 | 35.42 | 6.43 | 7.77 | 3.9 | 5.6 | 29.13 | 35.35 | 6.1 | 7.77 | 3.5 | 8.6 | 29.05 | 31.6 | 5.7 | 7.83 | 4.67 | 3.03 |
| 8/7/02 3:00 PM | 29.05 | 34.64 | 6.44 | 7.77 | 2.9 | 15.7 | 29.17 | 34.57 | 6.13 | 7.77 | 2.2 | 6 | 29.15 | 31.2 | 5.74 | 7.88 | 3.14 | 2.79 |
| 8/7/02 3:30 PM | 29.12 | 33.89 | 6.51 | 7.76 | 3.1 | 8.1 | 29.24 | 33.79 | 6.19 | 7.76 | 2.1 | 6 | 29.25 | 30.3 | 5.87 | 7.84 | 3.11 | 3.72 |
| 8/12/02 2:00 PM | 27.47 | 43.87 | 5.19 | 7.75 | 9.6 | 89.6 | 27.59 | 43.17 | 4.12 | 7.75 | 8.3 | 79.5 | 28.15 | 40.2 | 5.1 | 7.82 | 11.5 | 2.27 |
| 8/12/02 2:30 PM | 27.75 | 40.73 | 5.38 | 7.72 | 4.7 | 90.2 | 27.88 | 40.06 | 4.23 | 7.72 | 4.3 | 20.5 | 28.55 | 36.6 | 5.33 | 7.76 | 6.6 | 2.18 |
| 8/12/02 3:15 PM | 27.76 | 41.43 | 5.36 | 7.73 | 5.4 | 4.2 | 27.88 | 41.01 | 4.21 | 7.73 | 5.7 | 3 | 28.05 | 38.1 | 5.05 | 7.77 | 8.7 | 2.01 |
| 8/12/02 3:30 PM | 27.95 | 40.46 | 5.55 | 7.73 | 6.1 | 4.2 | 28.08 | 39.77 | 4.34 | 7.73 | 4.8 | 3.5 | 28.25 | 36.3 | 5.34 | 7.80 | 6.1 | 2.41 |
| 8/12/02 3:45 PM | 28.13 | 39.75 | 5.86 | 7.75 | 4.3 | 91.2 | 28.25 | 39.57 | 4.55 | 7.75 | 3.6 | 7.1 | 28.35 | 35.5 | 5.53 | 7.80 | 7.5 | 2.6 |
| 8/12/02 4:00 PM | 28.25 | 38.35 | 6.17 | 7.76 | 5.3 | 4.9 | 28.37 | 38.20 | 4.75 | 7.76 | 4 | 43.5 | 28.35 | 34.3 | 5.62 | 7.81 | 6.9 | 2.83 |
| 8/12/02 4:15 PM | 28.34 | 37.15 | 6.27 | 7.75 | 4.5 | 6.3 | 28.46 | 37.01 | 4.82 | 7.75 | 3.7 | 45.3 | 28.45 | 33.4 | 5.59 | 7.80 | 6.7 | 2.86 |
| 8/13/02 8:00 AM | 27.72 | 27.94 | 5.31 | 7.52 | 4.1 | 2 | 27.84 | 27.42 | 4.27 | 7.52 | 3.5 | 5.5 | 27.75 | 25.4 | 4.52 | 7.57 | 5.31 | 1.67 |
| 8/13/02 8:15 AM | 27.73 | 27.50 | 5.27 | 7.51 | 3.6 | 85 | 27.84 | 27.12 | 4.26 | 7.51 | 2.6 | 47.5 | 27.75 | 24.9 | 4.57 | 7.57 | 5.14 | 1.84 |
| 8/13/02 8:30 AM | 27.72 | 27.38 | 5.26 | 7.51 | 3.8 | 3.1 | 27.84 | 26.98 | 4.24 | 7.51 | 3.9 | 7.7 | 27.85 | 24.9 | 4.58 | 7.54 | 5.23 | 1.77 |
| 8/13/02 8:45 AM | 27.71 | 27.75 | 5.25 | 7.52 | 4.5 | 85 | 27.83 | 27.52 | 4.21 | 7.52 | 3.1 | 2.4 | 27.85 | 25.1 | 4.58 | 7.55 | 5.81 | 1.79 |
| 8/13/02 9:15 AM | 27.73 | 27.55 | 5.3 | 7.52 | 2.6 | 3.8 | 27.84 | 27.59 | 4.3 | 7.52 | 2 | 30.9 | 27.95 | 25.3 | 4.76 | 7.57 | 4.47 | 1.91 |
| 8/13/02 9:30 AM | 27.77 | 27.35 | 5.39 | 7.52 | 2.9 | 2.8 | 27.89 | 27.27 | 4.32 | 7.52 | 2 | 6 | 27.95 | 25.1 | 4.74 | 7.62 | 4.45 | 2.24 |
| 8/13/02 9:45 AM | 27.77 | 27.32 | 5.35 | 7.52 | 2.8 | 86.1 | 27.89 | 26.88 | 4.29 | 7.52 | 2 | 36.1 | 27.95 | 25.2 | 4.72 | 7.61 | 4.46 | 1.84 |
| 8/13/02 10:00 AM | 27.75 | 27.48 | 5.2 | 7.51 | 2.7 | 3.5 | 27.89 | 27.13 | 4.18 | 7.51 | 2.5 | 7.2 | 28.05 | 25 | 4.8 | 7.60 | 4.36 | 2.12 |

| | YSI AA | | | | | | YSI AB | | | | | | Reference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m/d/y hh:mm | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total |
| 8/13/02 1:00 PM | 27.71 | 37.42 | 4.96 | 7.65 | 5.7 | 81.7 | 27.83 | 37.38 | 3.86 | 7.65 | 3.3 | 52 | 27.85 | 31.7 | 4.54 | 7.63 | 5.1 | 1.7 |
| 8/13/02 1:15 PM | 27.7 | 39.14 | 4.98 | 7.68 | 4.4 | 3.5 | 27.82 | 38.73 | 3.88 | 7.68 | 3.3 | 34 | 27.85 | 35.1 | 4.52 | 7.69 | 6.6 | 1.82 |
| 8/13/02 1:30 PM | 27.69 | 39.86 | 5.1 | 7.70 | 4.3 | 3.1 | 27.81 | 39.27 | 3.93 | 7.70 | 3.2 | 38.2 | 27.85 | 35.8 | 4.56 | 7.71 | 6 | 1.79 |
| 8/13/02 1:45 PM | 27.68 | 40.51 | 5.07 | 7.71 | 4.8 | 4.7 | 27.79 | 40.58 | 3.89 | 7.71 | 4.2 | 46.3 | 27.85 | 35.6 | 4.58 | 7.71 | 6.3 | 1.8 |
| 8/13/02 2:15 PM | 27.67 | 41.04 | 5.08 | 7.71 | 4.5 | 84.2 | 27.78 | 41.09 | 3.85 | 7.71 | 3.6 | 56.3 | 27.85 | 36.7 | 4.52 | 7.67 | 7 | 1.84 |
| 8/13/02 2:30 PM | 27.65 | 41.69 | 5.07 | 7.72 | 4.7 | 3.4 | 27.77 | 41.59 | 3.85 | 7.72 | 4.1 | 4.8 | 27.85 | 37.6 | 4.44 | 7.72 | 5.5 | 1.9 |
| 8/13/02 2:45 PM | 27.62 | 42.87 | 5.06 | 7.73 | 6.1 | 3.4 | 27.74 | 42.56 | 3.82 | 7.73 | 5.4 | 2.2 | 27.85 | 38.1 | 4.48 | 7.74 | 8.1 | 1.96 |
| 8/13/02 3:00 PM | 27.62 | 42.92 | 5.02 | 7.72 | 7.3 | 3.3 | 27.77 | 41.93 | 3.82 | 7.72 | 5.4 | 9.4 | 27.85 | 38.6 | 4.55 | 7.74 | 7.25 | 1.95 |
| 8/23/02 8:30 AM | 27.83 | 0.48 | 3.06 | 7.15 | 3.9 | 38.4 | 27.88 | 0.48 | 2.94 | 7.16 | -0.4 | 38.1 | 27.75 | 0.456 | 1.97 | 6.84 | 8.02 | 21.2 |
| 8/23/02 8:45 AM | 27.85 | 0.48 | 3.12 | 7.15 | 4.3 | 37.5 | 27.87 | 0.48 | 2.93 | 7.15 | 0.1 | 37.4 | 27.35 | 0.453 | 1.98 | 6.78 | 9.2 | 20.5 |
| 8/23/02 9:00 AM | 27.88 | 0.48 | 3.15 | 7.15 | 4.4 | 39.4 | 27.9 | 0.48 | 2.81 | 7.15 | 0 | 36.4 | 27.85 | 0.456 | 2.51 | 6.82 | 8.19 | 20.5 |
| 8/23/02 9:15 AM | 27.99 | 0.48 | 3.46 | 7.18 | 4.7 | 39.7 | 27.98 | 0.48 | 3.23 | 7.17 | -0.7 | 37.4 | 27.95 | 0.449 | 2.04 | 6.78 | 8.45 | 20.2 |
| 8/23/02 9:30 AM | 28.22 | 0.48 | 3.85 | 7.19 | 4.3 | 36.1 | 28.1 | 0.48 | 3.49 | 7.19 | -0.5 | 38.4 | 28.15 | 0.454 | 3.1 | 6.90 | 8.54 | 20.5 |
| 8/23/02 9:45 AM | 28.27 | 0.48 | 3.96 | 7.20 | 5 | 41.5 | 28.21 | 0.49 | 3.67 | 7.21 | -0.3 | 41.8 | 28.05 | 0.451 | 2.73 | 6.89 | 7.59 | 19.5 |
| 8/23/02 10:00 AM | 28.47 | 0.48 | 4.52 | 7.25 | 3.5 | 35.4 | 28.45 | 0.49 | 4.19 | 7.24 | -0.5 | 39.7 | 28.45 | 0.453 | 3.88 | 6.94 | 7.17 | 19.9 |
| 8/23/02 10:15 AM | 28.6 | 0.49 | 4.85 | 7.26 | 4.3 | 37 | 28.59 | 0.49 | 4.63 | 7.27 | -0.5 | 36.5 | 28.45 | 0.452 | 3.25 | 7.01 | 6.9 | 19.4 |
| 8/23/02 1:30 PM | 32.01 | 0.51 | 13.68 | 8.58 | 5.3 | 45.9 | 31.94 | 0.52 | 13.13 | 8.53 | -0.5 | 41.4 | 31.75 | 0.449 | 10.25 | 8.33 | 7.1 | 24.6 |
| 8/23/02 1:45 PM | 32.64 | 0.52 | 13.51 | 8.61 | 4 | 39 | 32.36 | 0.52 | 13.46 | 8.65 | -0.5 | 39.1 | 32.65 | 0.447 | 10.09 | 8.41 | 8.63 | 25.4 |
| 8/23/02 2:00 PM | 32.88 | 0.52 | 14 | 8.72 | 4.8 | 37.8 | 32.52 | 0.52 | 13.73 | 8.66 | -0.7 | 99.3 | 32.55 | 0.448 | 10.7 | 8.30 | 6.66 | 23.9 |
| 8/23/02 2:15 PM | 32.98 | 0.52 | 14.07 | 8.70 | 4.2 | 38.1 | 33.01 | 0.52 | 13.75 | 8.72 | -0.7 | 36.5 | 32.95 | 0.447 | 10.74 | 8.43 | 6.88 | 26.5 |
| 8/23/02 2:30 PM | 33.16 | 0.52 | 13.67 | 8.67 | 4.3 | 36.9 | 33.28 | 0.53 | 13.36 | 8.66 | -0.7 | 36.4 | 32.95 | 0.447 | 10.9 | 8.28 | 7.13 | 21.7 |
| 8/23/02 2:45 PM | 33.28 | 0.53 | 14.1 | 8.73 | 4.2 | 37.8 | 33.33 | 0.53 | 13.75 | 8.75 | -0.5 | 33.4 | 33.25 | 0.446 | 11.4 | 8.39 | 6.48 | 23.9 |
| 8/23/02 3:00 PM | 33.58 | 0.53 | 14.51 | 8.83 | 4.2 | 37.3 | 33.52 | 0.53 | 14.54 | 8.85 | -0.8 | 35.2 | 33.55 | 0.449 | 12.1 | 8.38 | 8.11 | 21.7 |
| 8/23/02 3:15 PM | 33.66 | 0.53 | 14.73 | 8.85 | 4.2 | 33.9 | 33.77 | 0.53 | 14.7 | 8.87 | -0.6 | 35.7 | 33.45 | 0.448 | 11.7 | 8.42 | 6.78 | 22.6 |
| 8/26/02 2:00 PM | 30.81 | 0.50 | 12.72 | 8.59 | 5.1 | 30.7 | 30.75 | 0.50 | 12.26 | 8.53 | -1.4 | 105.3 | 30.65 | 0.44 | 11.45 | 8.49 | 7 | 21.6 |
| 8/26/02 2:15 PM | 30.84 | 0.50 | 13.78 | 8.71 | 4.7 | 34.7 | 30.83 | 0.50 | 13.28 | 8.67 | -0.8 | 29.5 | 30.65 | 0.447 | 11.8 | 8.37 | 7.3 | 18.7 |
| 8/26/02 2:30 PM | 30.77 | 0.50 | 14.19 | 8.75 | 4.1 | 33.6 | 30.79 | 0.50 | 13.82 | 8.73 | -0.9 | 101.8 | 30.75 | 0.442 | 12.3 | 8.57 | 8.1 | 18.5 |
| 8/26/02 2:45 PM | 31.02 | 0.50 | 14.48 | 8.78 | 4.3 | 32.8 | 30.94 | 0.50 | 14.18 | 8.77 | -1 | 29.9 | 30.75 | 0.44 | 12.5 | 8.59 | 7.9 | 17.5 |
| 8/28/02 2:15 PM | 26.26 | 0.38 | 7.08 | 7.27 | 8.4 | 36.8 | 26.25 | 0.39 | 6.78 | 7.21 | -1 | 93.5 | 26.25 | 0.386 | 6 | 7.04 | 7 | 14.8 |
| 8/28/02 2:45 PM | 26.46 | 0.38 | 8.4 | 7.35 | 8.7 | 30.2 | 26.54 | 0.40 | 7.28 | 7.24 | -0.5 | 24.1 | 26.65 | 0.377 | 6.85 | 7.17 | 6.5 | 14.3 |
| 9/5/02 1:15 PM | 25.49 | 0.27 | 8.56 | 7.94 | -0.4 | 0.4 | 25.6 | 0.27 | 8.11 | 7.96 | -2.9 | -0.2 | 25.55 | 0.261 | 6.91 | 7.77 | 0.95 | 0.597 |

| | YSI AA | | | | | | YSI AB | | | | | | Reference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m/d/y hh:mm | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total | Temp C | Cond. mS/cm | DO mg/L | pH | Turb. NTU | Chloro. total |
| 9/9/02 2:15 PM | 27.77 | 0.35 | 10.65 | 7.27 | 16.4 | 32.8 | 27.98 | 0.36 | 12.01 | 7.53 | 0.1 | 196.8 | 27.85 | 0.342 | 9.86 | 7.48 | 10.5 | 20.7 |
| 9/10/02 10:00 AM | 25.33 | 0.35 | 3.52 | 6.84 | 5.6 | 38 | 25.64 | 0.35 | 4.42 | 6.95 | 1.8 | 36.5 | 25.55 | 0.343 | 3.35 | 6.66 | 9.8 | 28.7 |
| 9/10/02 10:15 AM | 25.37 | 0.35 | 3.8 | 6.86 | 5.7 | 36.2 | 25.69 | 0.35 | 5.19 | 6.99 | 2 | 33.7 | 25.65 | 0.344 | 3.9 | 6.76 | 9.7 | 25.1 |
| 9/10/02 10:30 AM | 25.35 | 0.35 | 4.09 | 6.86 | 4.8 | 35.4 | 25.67 | 0.35 | 4.88 | 6.96 | 1.6 | 34.7 | 25.55 | 0.342 | 4.2 | 6.70 | 9.85 | 32.5 |
| 9/12/02 10:30 AM | 27.36 | 0.36 | 7.86 | 7.14 | 11.4 | 45.3 | 27.65 | 0.37 | 8.38 | 7.33 | 3.4 | 44.7 | 27.55 | 0.349 | 7.1 | 7.07 | 15 | 23.1 |
| 9/12/02 10:45 AM | 27.5 | 0.36 | 8.64 | 7.23 | 9.7 | 37 | 27.75 | 0.37 | 8.96 | 7.36 | 4.6 | 36.4 | 27.55 | 0.348 | 6.9 | 7.17 | 12.7 | 21.2 |
| 9/12/02 11:00 AM | 27.61 | 0.36 | 9.13 | 7.27 | 9.5 | 42.9 | 27.98 | 0.37 | 9.53 | 7.46 | 4.2 | 33.4 | 28.05 | 0.348 | 8.89 | 7.32 | 13.7 | 19.2 |
| 9/12/02 11:15 AM | 27.92 | 0.36 | 10.27 | 7.34 | 9.7 | 36.9 | 28.17 | 0.37 | 10.5 | 7.56 | 4.3 | 199.7 | 28.05 | 0.351 | 8.45 | 7.42 | 16.2 | 18.4 |
| 9/12/02 1:45 PM | 29.21 | 0.37 | 12.59 | 7.73 | 8.3 | 26.4 | 29.44 | 0.38 | 12.31 | 8.09 | 2.3 | 208.2 | 29.75 | 0.349 | 12.58 | 8.53 | 11.04 | 15.1 |
| 9/12/02 2:00 PM | 29.32 | 0.37 | 13.23 | 7.99 | 9.7 | 27.2 | 29.52 | 0.38 | 13.04 | 8.40 | 4 | 190.6 | 29.45 | 0.35 | 11.03 | 7.84 | 12.64 | 19 |
| 9/12/02 2:15 PM | 29.17 | 0.38 | 12.99 | 7.86 | 8.2 | 31.7 | 29.31 | 0.38 | 12.73 | 8.15 | 4.1 | 27 | 29.65 | 0.349 | 11.18 | 8.33 | 13.66 | 19.1 |
| 9/12/02 2:30 PM | 29.29 | 0.37 | 13.3 | 8.07 | 9.1 | 27.7 | 29.64 | 0.38 | 13.35 | 8.53 | 3.2 | 205.7 | 29.45 | 0.349 | 10.86 | 8.62 | 16.9 | 19.4 |
| 9/12/02 2:45 PM | 29.52 | 0.38 | 15.02 | 8.60 | 8.1 | 30.8 | 29.78 | 0.38 | 15.02 | 8.85 | 4.5 | 27.7 | 29.95 | 0.346 | 13.4 | 8.88 | 18.75 | 20.1 |
| 9/12/02 3:00 PM | 29.62 | 0.37 | 15.18 | 8.63 | 11.6 | 29.8 | 29.76 | 0.38 | 14.8 | 8.82 | 3 | 202 | 29.75 | 0.348 | 12.4 | 8.78 | 14.73 | 19.7 |
| 9/12/02 3:15 PM | 29.57 | 0.37 | 14.49 | 8.51 | 7.7 | 30 | 29.84 | 0.38 | 14.9 | 8.92 | 6.4 | 28.7 | 29.85 | 0.347 | 12.3 | 8.75 | 12.58 | 20.2 |
| 9/12/02 3:30 PM | 29.53 | 0.37 | 14.64 | 8.49 | 9.9 | 31.6 | 29.68 | 0.38 | 14.29 | 8.68 | 3.1 | 28.1 | 29.55 | 0.348 | 11.06 | 8.65 | 15.58 | 19.1 |

| | YSI AA | | | | | | YSI AB | | | | | | Reference | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Temp | Cond. | DO | | Turb. | Chloro. | Temp | Cond. | DO | | Turb. | Chloro. | Temp | Cond. | DO | | Turb. | Chloro. |
| m/d/y hh:mm | C | mS/cm | mg/L | pH | NTU | total | C | mS/cm | mg/L | pH | NTU | total | C | mS/cm | mg/L | pH | NTU | total |
| 9/19/02 4:00 PM | 28.37 | 38.92 | 7.52 | 7.97 | 0 | 4.9 | 28.24 | 38.48 | 7.44 | 7.94 | -2.1 | 3.4 | 28.65 | 35.3 | 7.34 | 7.97 | 1.59 | 2.37 |
| 9/19/02 4:15 PM | 28.92 | 39.37 | 7.75 | 7.97 | 0.3 | 2.9 | 29.04 | 39.07 | 7.82 | 7.95 | -2 | 3.9 | 28.95 | 35.5 | 7.31 | 7.94 | 2.13 | 2.41 |
| 9/20/02 9:00 AM | 24.59 | 36.48 | 7.25 | 7.81 | 0.4 | 5.4 | 24.7 | 36.15 | 7.31 | 7.80 | 4.7 | 4.6 | 24.65 | 35.2 | 6.87 | 7.81 | 1.51 | 2.2 |
| 9/20/02 9:30 AM | 24.69 | 36.55 | 7.23 | 7.79 | 68.4 | 58.5 | 24.8 | 36.23 | 7.28 | 7.78 | 43.8 | 51.3 | 24.75 | 35.8 | 6.77 | 7.79 | 60 | 23 |
| 9/20/02 11:00 AM | 25.35 | 36.30 | 7.16 | 7.82 | 196.2 | 153.9 | 25.46 | 36.72 | 7.18 | 7.80 | 129.7 | 139.3 | 25.35 | 35.9 | 6.78 | 7.80 | 133 | 47.5 |
| 9/20/02 4:00 PM | 29.05 | 39.62 | 6.86 | 7.87 | 20.2 | 11 | 29.13 | 39.72 | 6.9 | 7.85 | 11.5 | 10.5 | 29.15 | 35.8 | 6.65 | 7.84 | 19.4 | 5.05 |
| 9/20/02 4:15 PM | 30.11 | 40.29 | 7.09 | 7.86 | 17 | 9.4 | 30.22 | 40.49 | 7.18 | 7.84 | 8.7 | 8.9 | 30.25 | 36.4 | 7.03 | 7.83 | 18 | 4.7 |
| 9/23/02 10:15 AM | 24.95 | 38.49 | 7.1 | 7.84 | 0.6 | 5.2 | 25.06 | 38.18 | 7.23 | 7.83 | -1.7 | 4.3 | 25.05 | 37.2 | 6.9 | 7.79 | 2.3 | 2.45 |
| 9/23/02 10:30 AM | 24.99 | 38.50 | 7.06 | 7.84 | 0.7 | 4.6 | 25.1 | 38.21 | 7.16 | 7.83 | -1.8 | 5 | 25.05 | 37.6 | 6.89 | 7.83 | 2.35 | 2.71 |
| 9/23/02 11:00 AM | 25.05 | 38.56 | 6.98 | 7.85 | 2.5 | 5 | 25.16 | 38.26 | 7.07 | 7.83 | -1.8 | 3.9 | 25.15 | 37.8 | 6.94 | 7.83 | 2.4 | 2.62 |
| 9/23/02 1:45 PM | 26.01 | 39.36 | 6.98 | 7.88 | 0.3 | 5.4 | 26.11 | 39.03 | 7.05 | 7.87 | -1.5 | 3.7 | 26.05 | 38.3 | 6.72 | 7.84 | 1.45 | 2.29 |
| 9/23/02 3:30 PM | 27.43 | 40.50 | 6.78 | 7.90 | 0.4 | 4.1 | 27.52 | 40.15 | 6.94 | 7.89 | -2.2 | 2.9 | 27.45 | 38.4 | 6.72 | 7.88 | 1.35 | 1.71 |
| 9/23/02 4:30 PM | 28.51 | 41.78 | 6.72 | 7.84 | 0.4 | 3.8 | 28.7 | 41.75 | 6.7 | 7.84 | -2.4 | 2.9 | 29.55 | 38.1 | 6.5 | 7.71 | 2.05 | 2.31 |
| 9/24/02 9:30 AM | 24.46 | 38.57 | 3.84 | 7.39 | 0.7 | 4.1 | 24.58 | 38.25 | 3.88 | 7.38 | -1.6 | 3.2 | 24.55 | 37.7 | 3.71 | 7.28 | 1.9 | 1.84 |
| 9/24/02 9:45 AM | 24.45 | 38.55 | 4.77 | 7.44 | 1.4 | 4.5 | 24.57 | 38.24 | 4.81 | 7.43 | -1.1 | 3.9 | 24.55 | 37.7 | 4.54 | 7.36 | 1.9 | 3.41 |
| 9/24/02 11:00 AM | 27 | 0.62 | 6.9 | 8.70 | 4.2 | 2.2 | 27.11 | 0.61 | 7.01 | 8.67 | 0.3 | 1.7 | 27.15 | 0.68 | 5.96 | 8.40 | 6.25 | 2.03 |
| 9/24/02 1:30 PM | 27.11 | 1.40 | 7.63 | 8.17 | 1.2 | 1.6 | 27.23 | 1.33 | 7.75 | 8.17 | -1.3 | 0.7 | 27.25 | 1.304 | 6.4 | 7.97 | 2.46 | 2.91 |
| 9/24/02 3:15 PM | 27.18 | 1.51 | 7.64 | 8.09 | 6.9 | 2.6 | 27.3 | 1.48 | 7.8 | 8.09 | -0.5 | 1.5 | 27.25 | 1.406 | 6.55 | 7.89 | 4.22 | 2.79 |
| 9/24/02 4:30 PM | 28.4 | 2.69 | 7.26 | 8.15 | 2.6 | 0.9 | 28.52 | 2.66 | 7.34 | 8.13 | -0.4 | 0.6 | 28.45 | 2.67 | 6.22 | 8.04 | 3.87 | 1.34 |
| 9/25/02 11:00 AM | 24.27 | 3.10 | 8.11 | 7.95 | 1.5 | 1.1 | 24.38 | 3.08 | 8.17 | 7.94 | -1 | 0.7 | 24.35 | 3.35 | 6.88 | 7.63 | 1.91 | 2.23 |